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UNIVERSITY OF LONDON, UNIVERSITY COLLEGE

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BLOOD PRESSURE IN EARLY LIFE

A STATISTICAL STUDY

BY

PERCY STOCKS, M.D., D.P.H.
MEDICAL OFFICER TO THE DEPARTMENT

ASSISTED BY

M. NOEL KARN

WITH TWENTY-TWO DIAGRAMS IN THE TEXT
DRAWN BY IDA McLEARN

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BLOOD PRESSURE IN EARLY LIFE

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By Percy Stocks, M.D., D.P.H., assisted by M. Noel Karn

Diagrams by Ida McLearn

Introductory

There has been evident in recent years a tendency to discredit the usefulness of Blood Pressure measurements for purposes of clinical diagnosis. Whilst this may be only the inevitable reaction which usually follows the thorough testing of a new method for which extravagant claims have perhaps been made, it seems to us that it may partly be accounted for by factors which are remediable. Thus, in the first place, the normal ranges of pressures to be expected at various ages, particularly in early life, are only vaguely known and the numerous measurements which have been made on normal subjects have not been brought into line, nor any real attempt made to account for the apparent discrepancies between them.

This disagreement between the findings of various observers is partly due to lack of standardization of instrument and method (some observers measuring by palpation, others by auscultation), to differences in posture of the subjects examined, and to a failure to realize the importance of psychological influences in temporarily raising the blood pressure. Moreover, even at this date, seventeen years after the introduction of the simple auscultatory method of measuring the diastolic pressure, the investigation of blood pressure in this country is still largely confined to reading the systolic pressure alone. Lastly, the fact that the weight, height, pulse rate and muscular development of the subject have each an influence on his arterial pressure is only vaguely realized, and the amount of this influence has never been accurately computed as far as we are aware.

It was in the general hope of being able to produce a little more order out of this chaos that the following investigation was undertaken, but the principal aims in view were:

(1) To investigate the behaviour of the blood pressure during the period of puberty and adolescence, no continuous series of measurements on normal persons from childhood to adult life having been published by any one observer.

(2) To ascertain the normal range of systolic, diastolic and pulse pressures at ages from 5 to 40.

(3) To examine the inter-relation between these pressures, and their correlation with pulse rate, physical development, muscular strength, respiratory and psychological functions, social class and athletic habits of life.

(i) *Material.* The measurements were carried out on 1633 subjects, drawn from the following sources:

540 boys in London County Council Elementary Schools.
560 boys in London Secondary Schools.
69 boys of Merchant Taylors' School.
154 boys in Bristol Secondary Schools.
42 men on the Staff of the Virol Company's Factory.
154 Male Students of University College, London.
114 Female Students of University College, London.

In order to ensure the uniformity of method as far as possible, these measurements were all made personally, using the same instrument throughout.

In the case of the Bristol Secondary Schools the blood pressure was measured as a part of the routine School Medical inspections. In the London Council Schools the measurements were made with the cooperation of the School Medical Officer during a routine or "cursory" medical inspection. For permission to undertake this investigation I have to thank very warmly the authorities of the London County Council. In addition to the blood pressure and pulse rate, the boy's age, weight and height were recorded and anything of importance in the past medical history was noted. The strength of grip with each hand was also measured in a large number of the older boys by means of an elliptical dynamometer. The extent to which each boy took part in school games was afterwards ascertained where possible from the Headmaster. The observations on some of the elder boys at Merchant Taylors' School were made through the kind permission of the Headmaster and with the voluntary cooperation of the boys themselves. The staff of the Virol Factory were tested through the courtesy of the Virol Company. The vast majority of observations were made between the hours of 10 a.m. and 1 p.m. In the case of the students of University College, and some 40 of the boys, a much more complete series of tests which will be referred to later was carried out at the Anthropometric Laboratory of the Department of Applied Statistics.

Further details of the methods employed will be given under the appropriate headings.

(ii) *Definition of Terms, and Discussion of Technique.* Before proceeding to analyse our results it is advisable to clearly define what we mean by the various terms used, and to briefly summarize the more recent work which has been done on the question of blood pressure measurement and its bearing on the technique we have adopted.

It is obvious that, in order to maintain a continuous flow of blood through the arteries and capillaries into the veins and back to the heart, there must at any point of the circulatory system be an excess of fluid pressure over the atmospheric tension to which the body is subjected, and at any point in the arterial system an excess of pressure over that in the venous system. If the arterial system were perfectly elastic and offered no resistance to the passage of blood until the capillaries were reached, we should expect to find that, apart from the influence of gravity, the pressure at all

points in the arterial system was the same. As a matter of fact, Findlay (1)* has shown that in childhood this condition of affairs is approximated to, and the pressure in the brachial and digital arteries, for example, shows little difference, but in adult life as the arteries become more rigid the pressure falls off from the centre to the periphery.

We are not, however, greatly concerned with this fact since it is customary always to measure the pressure in one of the brachial arteries above the elbow. It has been asserted by some observers that the pressure in the right and left brachial arteries is not always the same, probably on account of the difference in length and course of the subclavian arteries. This is certainly the case in some pathological conditions (69). For this reason we have always taken our measurements on the left arm.

Again it has been shown by Hill (1895) that the pressure in the carotid artery in animals is increased by tilting from the horizontal to the head-down position, and similar passive (as well as active) changes in posture have been shown by Stephens (2), Barach and Marks (3), Henderson and Haggard (4), Barach (5), Ellis (6), and Lee (7), to produce changes in the brachial pressure in man, owing no doubt to the action of gravity. We shall refer to this point later, but in order to eliminate this factor all our subjects were kept in the sitting posture with the forearm resting on a table, flexor surface uppermost.

In the early days of blood-pressure determination, the minimal pressure which it was necessary to exert on the brachial artery in order to just obliterate the radial pulse at the wrist was ascertained by means of a sphygmomanometer consisting of an armlet, which could be inflated by air pressure, connected with a mercury manometer. The pressure so measured was assumed to be the maximal pressure in the brachial artery during the period of cardiac systole and was therefore termed the *systolic pressure*.

During every contraction of the ventricles the arterial tension rises to a maximal level, and during diastole falls to a minimal level, the latter being termed the *diastolic pressure*. Owing to the muscular tone of the arterial walls, and the resistance offered by the arterioles, this minimal level which is reached after closure of the aortic valves is still considerably in excess of atmospheric tension, but a satisfactory means of measuring this diastolic pressure was not available until Korotkoff (8) in 1905 described an auscultatory method of measuring pressure changes in the brachial artery. This consisted in applying a stethoscope over the artery just below the armlet, raising the pressure until the pulse was inaudible, and noting the various changes in tone which occur as the tension in the armlet was gradually relaxed.

This method was first used by Krylow (9) and was introduced into Britain by Oliver in 1910 (10).

Ettinger (11), Fischer (12), Gittings (13), Goodman and Howell (14), Swan (15), and others, showed that the tone changes which occurred as the pressure was released could be analysed into five periods or *phases*, and that the recording of the points marking the limits of these phases gave further valuable information in regard to the arterial tension. Briefly these changes of sound are as follows:

* Figures in brackets refer throughout to the corresponding entry-numbers in the Bibliography.

Points		Phases		Significance
1st	Sudden appearance of clear tapping sound		— —	Pressure in armlet just equal to systolic pressure
		1st	Clear tapping sounds	Always present, but strong, loud sounds are not always indicative of health
2nd	Change from clear to murmuring sound		— —	
		2nd	Murmurs and muffled sounds	Phases not always distinct. Strength and clearness of these phases is usually characteristic of a strong heart
3rd	Change to clear tones		— —	
		3rd	Clear sounds ...	
4th	Sudden change from clear to dull and muffled sounds		— —	This point is best measure of diastolic pressure according to experimental evidence
		4th	Muffled, dull tones ...	Not always present: often prolonged in cardiac incompetence
5th	Cessation of all sound		— —	According to some, this point gives a better measure of diastolic pressure

As regards the length of these phases and their significance, Goodman and Howell (14) maintain that in the normal person the ratio $\frac{\text{2nd} + \text{3rd}}{\text{1st} + \text{4th}}$ phases should be about $\frac{5}{4}$; that is, the 2nd + 3rd phases (which they claim to be a measure of "cardiac strength") should comprise about 55 % of the whole four phases. [Their figures gave the mean percentages: 1st phase 31·1 %, 2nd 44·4 %, 3rd 11·1 %, 4th 13·3 %.] Working on 400 normal army recruits, Bertrand-Smith (16) also found the $\frac{5}{4}$ ratio to hold good in the recumbent position, but the ratio was increased considerably after exercise. [His figures gave, before exercise, approximate mean values, 1st phase 25 %, 2nd 51 %, 3rd 13 %, 4th 11 %.] Sorapure (17) found from some 750 soldiers in training at Hampstead that the lengths of 1st, 2nd and 3rd phases gave an average ratio about 1 : 2 : 2, and that these intermediate phases were most pronounced between the ages of 23 and 30.

It is evident from these discordant results that the personal equation in defining the 2nd and 3rd points is considerable, and in our own experience these two points are so frequently indefinite, at any rate before the age of 20, that we have not attempted to record them in any of our measurements. Moreover their significance is doubtful, and they appear to us to be dependent to some extent on the pressure of the stethoscope and other manipulations of the instrument.

The 1st point, at which the first tap of the pulse becomes suddenly audible, has been shown by experiments on dogs (Warfield 18) to correspond very closely with the actual maximal pressure in the artery under examination, and Taussig and Cook (19) and others have shown that the pressure reading taken at this point gives a much more accurate index of the systolic pressure than is obtained by the palpatory method.

In our experience (having used both methods) the auscultatory technique for determining systolic pressure gives far more constant results in a given individual, and is not open to the serious objections that (1) an appreciable interval of time elapses

before the pressure wave passing the armlet reaches the wrist, during which time the manometer reading may have fallen several millimetres, (2) the radial pulse may, in many instances, be too feeble to be palpable until a considerable volume of blood is passing the armlet and the pressure in the latter is considerably reduced below the tension in the brachial artery.

To the comparative results of the two methods we shall refer later (see p. 7) and it will suffice to state here that in all except the first 150 cases we have used the 1st point in the auscultatory method as our index of systolic pressure, and we consider it much superior to the palpatory method. The latter, however, is sometimes useful as a check when a lack of definiteness in the 1st point leads to a suspicion that the stethoscope is not properly adjusted over the artery and may obviate a serious error in such cases; it is an easy matter to apply both methods simultaneously for this purpose.

There is still some controversy as to whether the 4th or 5th point is preferable as an index of the *diastolic pressure.* Warfield (18) (20) showed by experiments on dogs that the 4th point gives the closest approximation to the minimal pressure level. Further experimental evidence was given by MacWilliam, Melvin and Murray (21) (49) and by Oliver, and these investigators considered that it should be used in preference to the 5th point. In this conclusion they have been supported by Lange and Manswetowa (22), Zabel (23), Stone (24), Taussig and Cook (19), Hirschfelder (25), Kilgore (26), Williamson (27) and others. It is unfortunate that many other observers are not in agreement on this question, but many of those who advocated the use of the 5th point had not available at that time the experimental evidence we have referred to. Some still continue to use the 5th point (Mackenzie (28), Swan (15) and others) with resulting confusion in comparison of data, since the difference in readings may be considerable. Thus according to Goodman and Howell (14) the 4th phase should average about 6 mm. in length; a comparison between the parallel observations of Barach and Marks (29) on some 300 males (see Table 9) shows a mean difference between the 4th and 5th points of 5·6 mm.; Mackenzie's statistics (28) for 1831 males in whom both points were recorded also gave an average difference of 6 mm., whilst Bertrand-Smith (16) found an average difference of 5·1 mm. It is urged by some of these workers that the 4th point sometimes merges into the 5th and cannot then be defined as a separate point, and that it is therefore advisable for general work to always read the 5th point as the index of diastolic pressure. Apart from the fact that the experimental evidence is in favour of the 4th point as the best index, we fail to see why the occasional absence of the 4th phase is any reason for adopting the 5th point in all cases; on the contrary, since the 4th phase is very variable in length, giving all values from zero to about 50 mm. in extreme cases, it is more logical from this point of view to always read the 4th point when present, and when the 4th phase is absent to assume the 4th point coincident with the 5th. In our experience the 5th point has no advantage in definiteness, since frequently the dull pulse sounds gradually fade away instead of suddenly ceasing, and in some cases of aortic regurgitation these sounds do not cease even when the pressure in the armlet is reduced to zero, so that we should then have to say that the diastolic

pressure was zero or negative! We have therefore adopted the 4th point as our index of diastolic pressure in common with several recent investigators, and we advocate this as the standard method of measuring the diastolic pressure. We have dealt with this at some length, as it is obviously impossible to attempt any analysis of the diastolic pressure until we have defined a standard method of measuring it.

The *Pulse Pressure* (a term introduced by Erlanger and Hooker, and now well established) is the difference between the systolic and diastolic pressures. It represents the amplitude of the pressure wave which occurs in the artery under observation as a result of each contraction of the ventricle. The pulse pressure is therefore, other conditions being equal, a good index of the ventricular output at each systole, and the product of this amplitude with the pulse rate per minute is therefore a measure of the output of energy per minute if the volume of systole be assumed constant. Whilst the diastolic pressure is to some extent an index of the potential energy of the arterial system, the pulse pressure is in the same sense a measure of its kinetic energy, and the systolic pressure of its total energy. The latter is therefore a compound quantity, being the sum of two factors which are not necessarily related, since the diastolic pressure is largely a function of the arterial resistance, whilst the pulse pressure is chiefly dependent on the strength and rate of cardiac systole. The ratio between these pressures, as we shall see presently, shows large variations even in normal individuals, and, as is well known, still larger variations in disease. Since, however, the blood supply to the cardiac muscle itself depends upon the diastolic pressure, so that the heart's capacity for work is also a function of the diastolic pressure, and for other reasons which need not be detailed here, the two pressures react upon one another and are far from being independent (see p. 37).

(iii) *Factors affecting Blood Pressure.* In common with most physiological measurements the blood pressure of healthy persons shows considerable individual variations. Moreover, like other properties of the cardiovascular mechanism, such as the pulse rate, it is very sensitive to disturbing factors. It will be well to enumerate the various factors which have been shown to influence the readings obtained by the sphygmomanometer, and which must be taken into consideration in attempting to analyse our data. We shall then consider these in further detail and see how they can be eliminated or the amount of their influence estimated.

(1) Technique of measurement.
(2) Posture of subject, position of arm, muscular tonus and movements of arm.
(3) Time of day, recent meals or sleep, atmospheric pressure, heat and humidity, "rhythmic variations."
(4) Age.
(5) Pulse rate.
(6) Physical development.
(7) Race, social class, heredity.
(8) Muscular strength.
(9) Habits of life (sedentary or otherwise), diet, state of bodily fitness, recent physical exertion.

(10) Respiration.
(11) Emotional and psychological influences, mental alertness, temperament.
(12) Sex.
(13) Pathological conditions.

(1) Technique of Measurement.

It has been shown by several observers that the breadth of the armlet has some influence on the pressure readings obtained. Thus Faught (30) states that narrowing the armlet may raise the readings by as much as 6—10 mm. In most instruments now used, a standard breadth of 12 cm. has been adopted, and in all our observations we have used a Brunton Sphygmomanometer with 12 cm. cuff.

We have already referred to the difference between systolic pressure readings obtained by the palpatory and auscultatory methods. In our first 150 cases, which were measured in Bristol Secondary Schools, we used the former method, but concluding that the auscultatory method was much superior, we have used the latter for all subsequent work.

In order to determine more completely whether the difference between readings obtained by the two methods was affected by age, we made a duplicate series of readings on some 250 boys of ages 5 to 13, and the average readings for different age groups were as follows:

Age group	Mean age	No. of cases	Mean systolic pressure		Difference
			Palpatory method	Auscultatory	mm.
5	5	36	82·61	85·27	2·66
7—9	8	54	91·57	96·83	5·26
10—11	10·5	69	95·38	103·52	8·14
12	12	49	98·69	108·95	10·26
13—14	13·5	100	101·37	113·42	12·05
15—17	15·5	97	111·55	125·77	14·22

These figures indicate that the discrepancy between average readings obtained by the two methods progressively increases from 2—3 mm. at age 5 to about 14 mm. at age 16. From the latter age onwards we have other data at our disposal.

Thus the mean differences (for adults chiefly) have been:

Korotkoff (8) ... 10—12 mm.
Gittings (13) ... 16·7 mm. (61 cases)
Warfield (18) ... 6—14 mm.
Prendergast (31) ... 5—10 mm.
Swan (15) ... ... 10 mm. (200 cases, mostly abnormal)

Many of the cases included in the above series had cardiac disease, and their ages were very varied.

The best comparative material for normal adults is that of Kilgore (26), who made some 900 measurements by both methods on 314 males (ages 16—36, mostly 17—19)

in the recumbent position. From the distributions given in his curves we calculate the mean values for systolic pressure to be 118·5 (palpatory) and 131·2 (auscultatory), giving an average difference of 12·7 mm., a value not very different from our average of 14·2 mm. for ages 15—17.

We therefore conclude that 13—14 mm. is a fair estimate of the mean correction which should be applied to palpatory readings of systolic pressure in normal young male adults, whilst for boys the difference is progressively smaller with decreasing age to about 3 mm. at age 7.

At ages below 7 we have often experienced considerable difficulty in obtaining an auscultatory reading at all, but it is evident that in very young children the error entailed in substituting a palpatory measurement is not very considerable. We have excluded from all our curves and tables cases in which only a palpatory reading was obtained.

The method of obtaining the diastolic pressure has been already fully discussed, and in all our observations the 4th point (i.e. end of 3rd phase) was recorded for this purpose.

(2) Posture, Muscular Tonus.

The posture of the body whilst the blood pressure is being measured is of considerable importance.

The variations which occur on change of posture are partly caused by the effects of gravity on the circulation and partly by changes in the muscular tonus, which either by directly affecting the arterioles and thus altering the peripheral resistance, or by reflex vaso-motor mechanism reacting on the heart, produce compensatory alterations in pressure in the arteries. Barach and Marks (3) in 1913, experimenting on men of 15—30 years of age, showed that by passively rotating the body from the erect to the horizontal position, a rise in systolic and pulse pressure and a fall in diastolic pressure usually resulted. Henderson and Haggard (4) found in the case of 10 young men that the pulse rate was slowed on changing from erect to horizontal, and still further retarded in the head-down position, but the response in blood pressure was variable. Barach (5) in 1919, working on 48 adults, found a rise in systolic and a fall in diastolic and pulse pressures on changing from erect to horizontal.

All these were passive movements, but the effect of active change of posture has been investigated by several observers by measuring the blood pressure whilst lying down, sitting and standing. Their results are briefly summarized on p. 9.

As regards the systolic pressure these results seem to show that the effect of posture is variable in different individuals. Wheelon's results (34) show that the systolic pressure tends on the whole to be slightly higher in the standing or sitting than the recumbent posture, but the difference between the standing and sitting averages is not significant in view of the probable errors ($\pm$ 1 mm.). The diastolic average obtained by Wheelon was significantly higher in the standing than the sitting posture (82, 76), but there was no significant difference between sitting and lying. His pulse rate averages show a progressive rise from recumbent to standing positions.

In view of Crampton's (32) claim that the combined changes in systolic pressure and pulse rate on assuming the standing position afford a measure of vaso-motor tone, which is also an index of physical fitness, we have measured the blood pressures and

Author	Material	Systolic pressure	Diastolic pressure	Pulse pressure	Pulse rate	Pulse rate—pressure product
Stephens (2) 1904	20 male students	Average highest in recumbent position. Little difference between average sitting and standing	—	—	—	—
Crampton (32) 1913	Normal males	Higher standing than recumbent in fit persons, but may be lower in unfits	—	—	Rises on standing, reaction being greater in unfit persons	—
Sewall (33) 1919	A few normals	—	—	—	—	Higher when standing
Wheelon (34) 1921	66 male students 20—28	Average standing ... 122 „ sitting ... 120 „ lying ... 116	82 76 75	40 44 41	92 80 73	— — —
Lee (7) 1921	85 males av. age 18	May be higher or lower in standing than recumbent	—	—	—	—

pulse rates both in sitting and standing postures for 159 males (ages 17—34) and 43 females (ages 19—34). The reactions which occurred after rising to the erect position are summarized in Table 1, and are shown in greater detail in Tables 2, 3.

TABLE 1. *Circulatory Reaction on changing from Sitting to Standing Posture* (159 *males*, 43 *females*).

Variable	Nature of Reaction	Percentages		Mean change in each group		Mean change (all cases)		Average pulse rates (sitting)
		M.	F.	M.	F.	M.	F.	M.
SYSTOLIC PRESSURE	Rise exceeding 2 mm. ...	51·6	25·6	+ 9·9	+ 10·4	+ 3·27	− ·81	72·5 ± 1·1
	Change of 2 mm. or less	22·0	25·6	—	—			73·2 ± 1·6
	Fall exceeding 2 mm. ...	26·4	48·8	− 6·9	− 7·1			74·7 ± 1·5
DIASTOLIC PRESSURE	Rise exceeding 2 mm. ...	81·8	62·8	+ 12·7	+ 8·1	+ 10·19	+ 4·77	73·4 ± ·8
	Change of 2 mm. or less	14·5	30·2	—	—			69·9 ± 2·2
	Fall exceeding 2 mm. ...	3·7	7·0	− 6·7	− 5·0			73·1 ± 3·8
PULSE PRESSURE	Rise exceeding 2 mm. ...	9·6	7·0	+ 8·0	+ 5·0	− 6·94	− 6·05	—
	Change of 2 mm. or less	18·5	20·9	—	—			
	Fall exceeding 2 mm. ...	71·9	72·1	− 10·7	− 8·8			
PULSE RATE per min.	Rise exceeding 2 beats	75·2	76·9	+ 10·6	+ 10·9	+ 7·55	+ 7·90	—
	Change of 2 beats or less	20·4	13·9	—	—			
	Fall exceeding 2 beats...	4·4	9·2	− 9·3	− 5·0			
PULSE RATE —PRESSURE PRODUCT	Rise exceeding 125 ...	29·9	27·9	—	—	− 193	− 203	—
	Change of 125 or less ...	16·9	18·6	—	—			
	Fall exceeding 125 ...	53·2	53·5	—	—			

A study of these tables leads to the following conclusions:

(i) *Systolic pressure.* On assuming the erect posture the systolic pressure may

rise or fall or remain stationary. Our cases showed a rise of more than 2 mm. to occur in about 52 °/。 of males and 26 °/。 of females, whilst a fall of over 2 mm. occurred in

TABLE 2. *Reaction of Systolic and Diastolic Pressures on changing from Sitting to Standing Posture. (Bracketed Figures are Females.)*

CHANGE IN SYSTOLIC PRESSURE

Change in Diastolic Pressure		Rise					Fall			Totals
	mm.	18—22	13—17	8—12	3—7	+2 to −2	3—7	8—12	13—17	
Rise	mm. 33—37	—	—	1	—	—	—	—	—	1
Rise	28—32	—	—	1	—	—	1	—	—	2
Rise	23—27	1	5	1	2	—	—	—	—	9
Rise	18—22	3	4	4	2	3	—	—	1	17
Rise	13—17	—	2 (3)	11	5	6	9	—	—	33 (3)
Rise	8—12	(1)	2 (1)	9 (1)	6 (3)	11 (1)	3 (2)	2 (2)	—	33 (11)
Rise	3— 7	—	2	4	11 (1)	10 (6)	4 (4)	4 (2)	—	35 (13)
	+2 to −2	1	2	—	3 (1)	4 (4)	11 (5)	1 (2)	1 (1)	23 (13)
Fall	3— 7	—	—	—	—	—	1 (2)	2 (1)	1	4 (3)
Fall	8—12	—	—	—	—	1	—	1	—	2
	TOTALS...	5 (1)	17 (4)	31 (1)	29 (5)	35 (11)	29 (13)	10 (7)	3 (1)	159 (43)

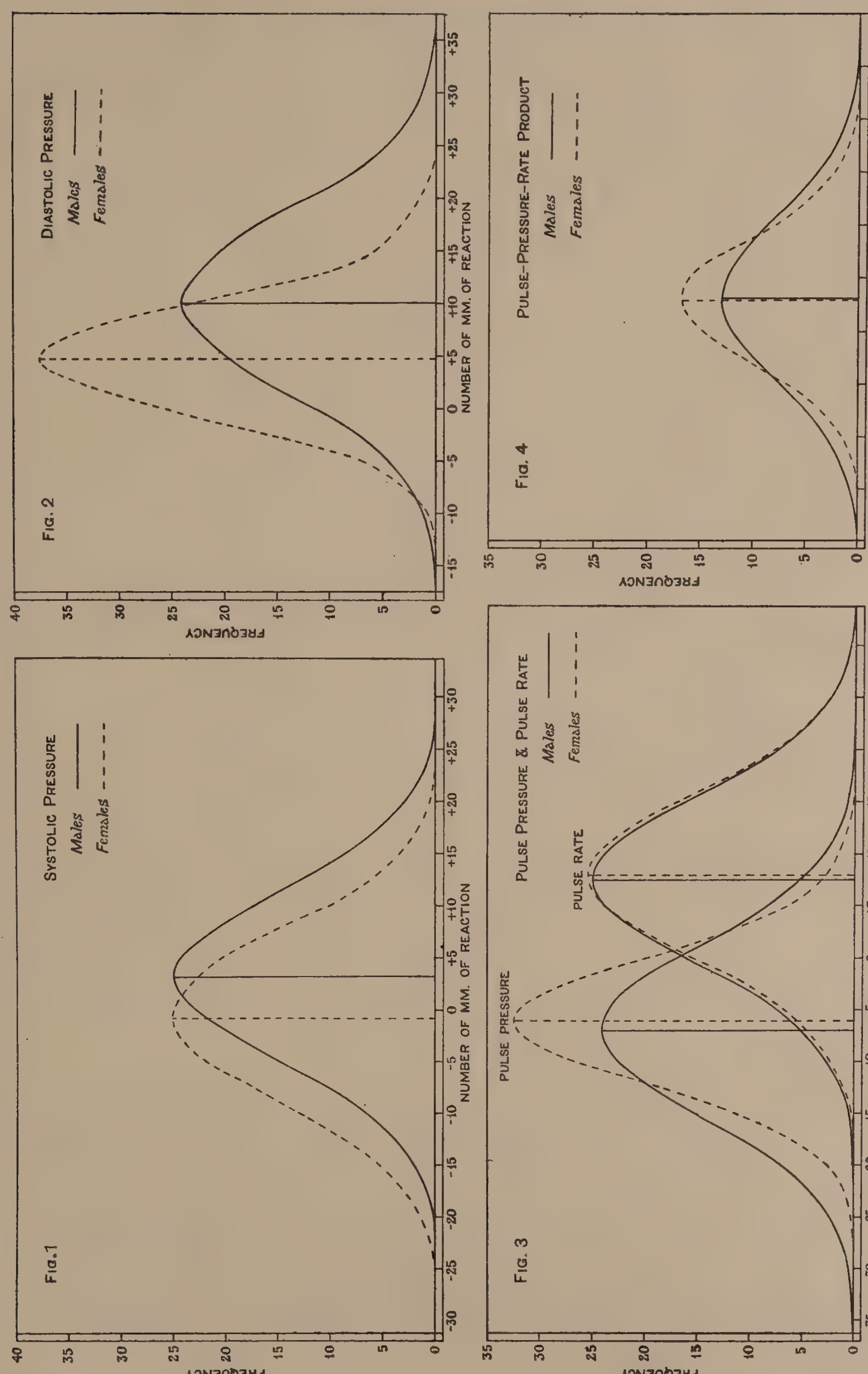
TABLE 3. *Reaction of Pulse Pressure and Pulse Rate on changing from Sitting to Standing Posture. (Bracketed Figures are Females.)*

CHANGE IN PULSE PRESSURE

Change in Pulse Rate		Rise					Fall							Totals
	mm.	18—22	13—17	8—12	3—7	+2 to −2	3—7	8—12	13—17	18—22	23—27	28—32	33—37	
Rise	per minute 33—37	—	—	—	—	—	1	—	—	1	—	—	—	2
Rise	28—32	—	—	—	—	—	1	1	—	—	—	—	—	2
Rise	23—27	—	—	—	—	(1)	1 (1)	—	1 (1)	—	—	—	—	2 (3)
Rise	18—22	1	—	—	—	1	2 (2)	—	4	1	—	—	—	9 (2)
Rise	13—17	—	—	1	2 (1)	2 (1)	3 (2)	5 (1)	5 (1)	—	—	—	1	19 (6)
Rise	8—12	—	1	—	1 (1)	7	13 (4)	8 (2)	5 (1)	2 (1)	—	—	—	37 (9)
Rise	3— 7	—	—	1	3	11 (4)	11 (3)	7 (3)	6 (2)	6 (1)	1	1	—	47 (13)
	+2 to −2	—	—	1	3 (1)	7 (1)	11 (3)	5 (1)	4	1	—	—	—	32 (6)
Fall	3— 7	—	—	—	—	(2)	2 (1)	1 (1)	—	1	—	—	—	4 (4)
Fall	8—12	—	—	—	—	1	—	—	—	—	—	—	—	1
Fall	13—17	—	—	—	—	—	—	1	—	—	—	—	—	1
Fall	18—22	—	—	1	—	—	—	—	—	—	—	—	—	1
	TOTALS	1	1	4	9 (3)	29 (9)	45 (16)	28 (8)	25 (5)	12 (2)	1	1	1	157 (43)

about 26 °/。 of males and 49 °/。 of females; a rise is therefore the more common in males and a fall the more usual in females, the mean reactions for all cases being respectively +3·27 and −·81 mm.

REACTIONS IN BLOOD PRESSURE ON CHANGING FROM SITTING TO STANDING POSITION



FIGS. 1—4.

The totals in Table 2 indicate that the systolic pressure reaction both in males and females ranges from a fall of about 15 mm. to a rise of 20 mm., and that the distribution of amount of reaction roughly approximates to the normal type of frequency curve. In Table 4, where all the figures have been reduced to percentages of all cases (in order to facilitate comparison of the sexes), the observed and calculated percentage frequencies for successive intervals of 5 mm. of reaction are tabulated, the latter being obtained by fitting normal curves to the observations. These curves are shown in Fig. 1, and resemble each other closely as regards the range of reaction, the values of σ being 8·06 mm. for males and 7·99 for females. As already indicated, the mean reaction for males is about 4 mm. on the positive side of that for females. All that we can say in regard to the amount of reaction met with in any individual is that a rise of systolic pressure exceeding 27 mm. or a fall exceeding 21 mm. in a male, and a rise exceeding 23 mm. or a fall exceeding 25 mm. in a female, are most probably pathological.

In order to test whether the nature of the reaction had any relation to the pulse rate of the subject, we have given in the last column of Table 1 the mean pulse rates for the groups showing a rise of over 2 mm., a change of 2 mm. or less, and a fall of over 2 mm. These means do not differ significantly in relation to their probable errors in the case of males, but it was noticeable that the five cases with an initial pulse rate over 100 per minute all showed a fall in systolic pressure on standing (giving a mean reaction of $-3·7$ mm.), and it is these cases which account for the slightly higher average pulse rate of the last group. In the case of females we also failed to find any significant relation between the initial pulse rate and the rise or fall of systolic pressure on standing.

As regards the influence of physical fitness on the reaction, Crampton (32) has maintained that the changes in systolic pressure and pulse rate which occur on rising from the recumbent to the erect posture together furnish an index of the "fitness" or "unfitness" of the person examined. He proposed an index which, briefly stated, was as follows: taking 75 as the index number for zero reaction both in systolic pressure and pulse rate, subtract 5 for each 4 beats rise in pulse rate, and add or subtract 5 for each 2 mm. rise or fall in systolic pressure. (He based this on the assumption that a perfectly fit person will react with a rise of 10 mm. in systolic pressure and little or no change in pulse rate, giving index = 100, whereas a person so unfit that syncope occurs on standing will show a fall in systolic pressure about -10 mm. with a rise in pulse rate of about 40 beats, giving index = 0.)

We have made no measurements in the recumbent position, but as most of the reaction takes place during the last phase of the movement, viz. from sitting to standing, we should expect to find a similar relation to hold good in our own experiments.

On the assumption that muscular strength and efficiency in a muscular fatigue test must be some indication of a person's physical fitness we have sought to test this point for males by dividing them into two groups, (i) those giving a reaction from sitting to standing corresponding to an index as defined by Crampton of over 70, (ii) those giving a reaction equivalent to an index below 70. We have then calculated the

TABLE 4. *Circulatory Reaction on Change of Posture (see Figs. 1—4). Frequency Distribution (observed and calculated Percentages).*

	*	SYSTOLIC PRESSURE				DIASTOLIC PRESSURE				PULSE PRESSURE				PULSE RATE				P.P. × P.R. product			
		Males		Females		Males		Females		Males		Females		Males		Females		Males		Females	
		Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.	Obs.	Calc.
Increase on standing	Over 35	—		—		—	·13	—		—		—		—	·03	—		1·95	·61	—	
	35	—		—		·63	·69	—		—		—		1·27	·21	—		·65	·83	—	
	30	—		—		1·26	2·82	—		—		—		1·27	1·20	—	1·48	·65	1·68	—	
	25	—	1·91	—	·46	5·66	8·09	—		—		—		1·27	4·49	6·9	4·71	0	3·05	—	2·27
	20	3·14	5·38	2·3	1·93	10·69	16·27	—	2·61	·64	·34	—		5·73	11·59	4·6	12·13	1·95	5·00	4·6	3·37
	15	10·69	12·90	9·3	6·41	20·75	22·92	6·9	13·44	·64	1·64	—		12·11	20·42	13·9	21·15	5·19	7·37	2·3	6·47
	10	19·50	21·31	2·3	14·55	20·75	22·61	25·5	32·21	2·55	5·42	—	3·61	23·57	24·60	20·9	24·92	6·49	9·83	4·6	10·44
	5	18·24	24·25	11·6	22·61	22·02	15·62	30·2	33·47	5·73	12·64	7·0	12·64	29·93	20·26	30·2	19·86	12·99	11·79	16·2	14·23
	0	22·02	19·00	25·5	24·05	14·46	7·57	30·2	15·08	18·47	20·65	20·9	26·97	20·38	11·42	13·9	10·71	16·89	12·77	18·6	16·34
Decrease on standing	5	18·24	10·26	30·4	17·50	2·52	2·56	9·3	2·94	28·66	23·64	37·1	30·76	2·55	4·39	9·2	5·04	17·54	12·48	18·6	15·82
	10	6·29	3·82	16·2	8·71	1·26	·72	—	·25	17·83	19·08	18·6	18·75	·64	1·15	—		11·04	10·99	20·9	12·92
	15	1·89	1·17	2·3	3·78	—		—		15·92	10·79	11·6	6·11	·64	·21	—		8·42	8·73	4·6	8·90
	20	—		—		—		—		7·64	4·28	4·6	1·16	·64	·03	—		5·19	6·25	—	5·17
	25	—		—		—		—		·64	1·19	—		—		—		5·19	4·04	2·3	2·52
	30	—		—		—		—		·64	·23	—		—		—		2·60	2·36	2·3	1·05
	35	—		—		—		—		·64	·04	—		—		—		·65	1·24	4·6	·50
	40	—		—		—		—		—		—		—		—		1·30	·59	—	
	Over 40	—		—		—		—		—		—		—		—		1·30	·39	—	

* For the P.P. × P.R. product this scale must be multiplied by 50.

mean strength of grip and efficiency in maintaining a pull over a period of 30 seconds (see our section (8)) for the men in these two groups, with the following results:

	Mean grip (R. and L. hands) average	Mean total pull (7 readings at 5 second intervals)
Group (i): Index over 70 ...	$40{\cdot}0 \pm {\cdot}9$ (kilos)	381 ± 9 (lbs)
„ (ii): Index 70 or less ...	$42{\cdot}5 \pm {\cdot}9$ (kilos)	399 ± 9 (lbs)

It will be seen that the differences are not significant, but if anything those giving the lower index were slightly more efficient in both tests. Unless we suppose that efficiency in tests of muscular strength and endurance of this kind is not positively related to physical fitness, it is difficult to reconcile these results with Crampton's theory. At any rate, though we cannot say that they disprove it, we can definitely state that these and other observations of ours lend no support to the idea that such an index is of any value in assessing physical fitness.

(ii) *Diastolic Pressure.* As indicated in Table 1, the diastolic pressure showed a rise of over 2 mm. in 82 °/。 of males and 63 °/。 of females, and a fall of over 2 mm. in 4 °/。 of males and 7 °/。 of females, the mean reactions in all cases being $+10{\cdot}19$ mm. for males and $+4{\cdot}77$ mm. for females.

The distributions of these reactions are shown in Table 2, and the observed and calculated normal frequency distributions in Table 4, the latter being shown graphically in Fig. 2.

The curves for the sexes show a marked difference both as regards the average reaction and the range of reactions met with. Thus for males the mean reaction was $+10{\cdot}19$ mm. and $\sigma = 8{\cdot}25$ mm., for females mean $= +4{\cdot}77$ and $\sigma = 5{\cdot}27$. A considerable rise in diastolic pressure on standing is evidently exceptional in females but not in males; thus we met with no case of a rise exceeding 17 mm. in a female, whilst 18 °/。 of males gave a rise of this magnitude or over. As regards the possible fall there is less difference between the sexes, but we never observed a fall of more than 10 mm.

We may say therefore that in males a rise exceeding 35 mm. or a fall exceeding 14 mm., and in females a rise exceeding 20 mm. or a fall exceeding 11 mm. may be regarded as probably pathological. It is clear from Table 2 that the signs of the reactions occurring in systolic and diastolic pressures are positively correlated; thus we never observed a fall in diastolic pressure to accompany a rise in systolic pressure, though the converse occurred in 15 °/。 of males and 23 °/。 of females. As in the case of systolic pressure, there is no evident relation between the diastolic reaction and the initial pulse rate.

(iii) The *Pulse Pressure* was smaller in the standing than the sitting posture (by more than 2 mm.) in about 72 °/。 of males and females, and showed an increase of over 2 mm. in 10 °/。 of males and 7 °/。 of females, the mean reactions for all cases being respectively $-6{\cdot}94$ mm. and $-6{\cdot}05$ mm. for the two sexes. The distributions are given in Table 3 and Table 4, and the normal frequency curves which have been fitted to the observations are shown in Fig. 3. It will be seen that the range of reaction in

males was from a rise of 20 mm. to a fall of 35 mm. ($\sigma = 8{\cdot}28$ mm.), the range being rather less for females ($\sigma = 6{\cdot}15$ mm.).

Table 3 indicates a negative correlation between the changes in pulse pressure and pulse rate, and the tendency for changes in these two factors to compensate one another is indicated in Fig. 3, where the distribution for the pulse-rate reaction has been plotted on the same diagram.

(iv) *Pulse Rate* increased on standing by more than 2 beats per minute in about 76 °/ₒ of cases of each sex, and a slowing of the pulse of more than 2 beats per minute only occurred in 4·4 °/ₒ of males and 9·2 °/ₒ of females, the mean reaction for all cases being an increase of about 8 per minute in both sexes, the values of σ being 7·98 and 7·86 respectively. Wheelon (34) found an average rise of 12 per minute. For a series of Air Force Cadets, Officers and Civilians, the mean pulse rates, as given by Greenwood and Newbold in a paper read to the Society of Biometricians and Mathematical Statisticians, were as follows:

	Sitting	Standing	Increase
Cadets (90): Average age 18·7 ...	76·6	86·9	10·3
Officers (267): „ „ 23·6 ...	74·3	83·2	8·9
Civilians (56): „ „ 24·8 ...	73·2	80·0	6·8

giving a mean increase for 413 males of about 8·9, a figure similar to our own.

The pulse pressure × pulse rate product (which averages about 3000 in normal individuals) may rise or fall in individual cases, as shown in the distribution in Fig. 4, but on the average remains fairly constant, the mean change in this product for all cases being a fall of 200 in each sex. This is due to the average fall in pulse pressure being almost compensatory to the average rise in pulse rate. The wide range in Fig. 4 indicates, however, that this compensation is by no means always even approximated to in individual cases. Thus changes in this product amounting to as much as 2500 were met with in two instances, but those showing a large drop in the value of this product were chiefly subjects with unusually high pulse rates (possibly due to nervousness in some cases) which fell to a more average level on standing. In about 45 °/ₒ of males and 35 °/ₒ of females the change in this product was found to exceed 500.

It is therefore evident that the changes which occur in blood pressure on change of posture are of a complex nature and depend upon conditions of the vaso-motor mechanism which are obscure. All we can definitely say is that *a rise in pulse rate and in diastolic pressure with a decrease in pulse pressure occurs in most cases on rising from the sitting to the standing posture, but a reversal of these reactions does not seem to be incompatible with physical fitness.* The changes in systolic pressure are variable and the claim that they furnish any index of physical fitness is not supported by our observations.

The effect of *muscular tonus* alone in modifying the systolic and diastolic pressures

can be demonstrated by remaining in a sitting posture and voluntarily throwing the lower limbs into a state of muscular tension; it is possible by so doing to raise the pressure in the brachial artery by several millimetres.

Similarly the pressure may be reduced by voluntary relaxation; and this effect is no doubt partly responsible for the lower level of pressure found in the average Hindoo (see section (7) below).

Muscular movements of the arm, such as clenching of the fist, may also cause variations of a few millimetres. We have not observed any considerable difference between readings taken on right and left arms.

Having thus demonstrated the importance of posture and the impossibility of adequately correcting for it, we would strongly advocate the use of a *standard posture* in all blood pressure determinations if these are to be made comparable with one another.

The posture we have adopted as our standard in all the measurements in this investigation is as follows:

Subject seated comfortably on a chair.

Sphygmomanometer armlet round left arm above the elbow; left forearm extended on a table in front of subject, with elbow slightly flexed and extensor surface of forearm and back of hand resting on the table.

Muscles of arm and hand relaxed.

(3) Time of Day and External Conditions.

Diurnal Variation. It has been found that a slight increase in systolic pressure occurs during the day and that a temporary rise occurs after meals. Thus Faught (30) states that, commencing with a depression of 10—12 mm. in the early morning, the systolic pressure gradually rises to a maximum between 3 p.m. and 7 p.m. Erlanger and Hooker (35) found the systolic to be more affected than the diastolic pressure by the diurnal factor, so that the pulse pressure also increased to a maximum with systolic pressure. Brooks and Carroll (36) found by measurements on 29 normal individuals that a considerable fall in systolic pressure occurred during the first few hours of sleep, amounting to 20 mm. or more, and that it remained at a low level for some hours after waking. Weysse and Lutz (37) found that the diastolic pressures of 10 normal males remained very uniform throughout the day and were not appreciably affected by the taking of meals; the systolic and pulse pressures and pulse rate all showed a gradual increase during the day and a temporary rise after each meal (reaching a maximum about half an hour after). Loeper (38) found that the increase following meals persisted for 15—45 minutes and that the pressure then fell to a sub-normal level. Dearborn (39) concluded from many observations made at short intervals on the same cases that there was some indication of the existence of rhythmic pressure variations having a wave-length of 10—20 minutes.

In order to eliminate the effect of diurnal variations as far as possible, practically all our measurements of boys were carried out in the morning between 10 a.m. and 12.30 p.m. This, however, was not always the case with College students, some

being measured between 2 and 5 p.m.; on dividing these into morning and afternoon groups we obtained the following mean values for male British students, the average age being approximately 22½ in each case:

	No.	Systolic Pressure	Diastolic	Pulse Rate
Morning average ...	54	$127{\cdot}7 \pm 1{\cdot}2$	$84{\cdot}5 \pm 1{\cdot}2$	$70{\cdot}7 \pm 1{\cdot}2$
Afternoon average ...	43	$131{\cdot}9 \pm 1{\cdot}4$	$84{\cdot}5 \pm 1{\cdot}4$	$73{\cdot}5 \pm 1{\cdot}3$

These show no difference between the diastolic averages, but an apparent difference of about 4 mm. in systolic pressure and 3 beats per minute in pulse rate. These results agree with the findings of other observers already quoted, though taken by themselves the differences in relation to the probable errors could not be emphasized as significant.

Atmospheric Conditions and Climate. It has been shown that atmospheric heat and humidity lower the blood pressure, and *vice versâ*. Thus Oliver (40) states that a spell of hot weather may lower the systolic pressure by as much as 10—20 mm.

Southern races tend to have lower pressures than those living in colder climates, as was shown by McCay in Calcutta, where he found a mean systolic pressure of 100 mm. for natives by the palpatory method.

We shall refer to racial differences in a later section.

Pomeroy (41) found that a reduction of atmospheric pressure caused a fall in systolic and diastolic pressures and a slight rise in pulse rate. Gardner and Hoagland (42) found that a year's residence at an altitude of 6000 ft. or more resulted in a slight lowering of systolic pressure. Smith (43), however, from observations on 250 cases at 6000 ft. altitude, concluded that any differences which he found might be accounted for by other factors.

(4) Age.

It has been a matter of common knowledge for many years that blood pressure rises with increasing age in both sexes. Since the vast majority of our observations, and those of others, have been made on males, we propose to deal with the male sex alone under this and the next seven headings, and then to consider the sexual differences in a separate section (see Section (12) below).

The majority of the published blood-pressure measurements have been made on adults, a few have been made on school children up to 14, whilst the data for ages 15 to 20 are very scanty. It was partly for this reason that we concentrated our attention particularly on the years of adolescence, since the behaviour of the blood pressure during this period has not been thoroughly investigated. From our own observations also it has appeared to us that the "rules" commonly given in text-books for finding the "normal" pressure at any age (which almost invariably suppose a uniform increase to occur throughout life) are founded on assumptions which are not supported by the facts, at any rate before the age of 40.

We have therefore endeavoured to establish the true form of the age curve up to middle life. The problem has been complicated by the fact (see Section (7) below) that differences in race and social class have considerable influence on the average pressure. Racial differences appear indeed to be so great that we have eliminated all but British males from our tables and age curves, and have dealt with other races separately. As regards social class, whilst we have combined all our data to obtain the age curves, which may therefore be taken to represent an average social grade, we have also separated the material as far as practicable in order to demonstrate the influence of social selection on blood pressure. This will be discussed fully in Section (7).

In examining the relation with age it will be most convenient to deal with each portion of the arterial pressure separately, and we shall first attempt in each case to analyse the various data which may be useful for comparison before detailing our own results.

(i) *Systolic Pressure.*

Previous Work. The most useful comparative data have been collected in Table 5, and for reasons already given we have separated these into groups according to the method and posture used, where this is known.

It is at once obvious that these results show considerable discrepancies amongst themselves. The measurements of Woley (47) and Melvin and Murray (48) were made by palpation and naturally give lower values. The statistics of the Mutual Insurance Co. and the Prudential Assurance Co. of America, analysed by Fisher (51) and Mackenzie (28), though including a few cases aged 15—25, principally consist of males over 40; moreover they suffer from the two objections that the measurements were made by a considerable number of observers using various methods, and that the cases were selected, since those with blood pressures outside certain limits were rejected by these companies. Mackenzie's series of 1835 cases, measured by the auscultatory method, is of more value, but is still open to the same objections.

Using an Erlanger sphygmomanometer combined with the auscultatory method, Judson and Nicholson (50) measured the systolic pressure of school children from 4—15 years of age in the recumbent posture, and found a continuous rise from 90 mm. at age 4 to 106 mm. at age 14. Katzenberger (53) in the same year (1913) measured the systolic pressure of a number of school children in Germany and found an increase from 93 at age 4 to 119 mm. at 14 (auscultatory method). Using the same method Stone (24) found from 35 normal males under 40 an average systolic pressure of 120 mm., and for 26 males over 40 an average of 127 mm., but details of the ages are not stated. Barach and Marks (29) from 656 young adults of average age 20—21 (range 15—30) obtained a mean value 131·1 (as we calculate from their figures).

Up to 1916 this evidence showed that (1) there is a continual rise in systolic pressure from 3—15; (2) the mean pressure between ages 30—60 is some 5 mm. higher than the mean from 16—30; (3) from Fisher's statistics there appeared to be only a very small rise between 20 and 40, amounting to 3 or 4 mm.

It appears to us, therefore, that the evidence for the "rules" laid down by Faught

TABLE 5. *Summary of Mean Systolic Pressures for different Ages as found by various Observers (Males).*

Author	Material	Technique	Posture	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26—30	31—35	36—40	41—45	46—50	51—55	56—60
Woley (47) 1910	1000 males	PALPATORY	?	—	—	—	—	—	—	—	—	—	—	—	119	←——	——	——	——	——	122 (av	erage)	——	——	——	——→	←——12	7——→	←——13	0——→	←——13	2——→
Melvin & Murray (48) 1914...	—	,,	?	←——	——	——	——	——	107 (av	erage)——	——	——	——	——	——→	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Alvarez (46) 1920	2930 male students	,,	Recumbent	—	—	—	—	—	—	—	—	—	—	—	—	126·3	128·2	127·8	126·2	126·3	125·4	126·2	126·3	130·0	126·9	—	—	—	—	—	—	—
Fisher (51) 1911	13,067 males (420 under 40) Insurance data	Probably mostly palpatory	Various	—		—	—	—	—	—	—	—	—	—	←——	——	118 (av	erage)——	——→	←——	——	123·5	——	——→	←——125	·6——→	125·5	126·2	128·3	130·5	132	134·5
Mackenzie (28) 1920 ...	5018 males Insurance data	,,	,,	—	—	—	—	—	—	—	—	—	—	—	←——	——	——	——	——	125 (av	erage)——	——	——	——	——	——→	←——	——	——13	0——	——	——→
Stone (24) 1913	61 males	AUSCULTATORY	?	—	—	—	—	—	—	—	—	—	—	—	←——	——	——	——	——	——	(under	40) 120	——	——	——	——	——	——→	←——	127 (ov	er 40)——	——→
Barach & Marks (29) 1914 ...	646 young adults	,,	?	—	—	—	—	—	—	—	—	—	—	—	←——	——	——	——	(Avera	ge age	20—21	)131——	——	——	——	——→	—	—	—	—	—	—
Sorapure* (17) 1918... ...	769 soldiers under training	,,	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—	132	134	134	136	138	133	133	133	132	130	130	—	—	—	—
Mackenzie (28) 1920... ...	1835 males Insurance data	,,	?	—	—	—	—	—	—	—	—	—	—	—	←——	——	——	——	——	122 (av	erage)——	——	——	——	——	——→	←——	125	——→	←——	131	——→
Judson & Nicholson (50) 1913	School children	,,	Recumbent	90——	——92——	——→	←93——	——94——	——→	←95——	——99→	←100——	——103→	106·1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Kilgore (26) 1918	314 young males	,,	,,	—	—	—	—	—	—	—	—	—	—	—	—	←——	——	——	——	——131	(mostly	17 to	19)——	——	——	——	——→	—	—	—	—	—
Bertrand-Smith (16) 1918 ...	400 aviation recruits	,,	,,	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	←——	——	(Avera	ge age	24·2)	127·7	——	——	——	——→	—	—	—	—
Lee (7) 1921	662 students	,,	,,	—	—	—	—	—	—	—	—	—	—	—	(Avera	ge age	18)	120	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Katzenberger (53) 1913 ...	School children	,,	?	93——	——	——	——	increas	ing to——	——	——	——	——	——119	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Smythe (52) 1919	100 cadets	,,	Sitting	—	—	—	—	—	—	—	—	—	—	—	—	—	—	121·2	←——	127·1	——→	←——	——	126	——→	123·9	125·1	125·3	—	—	—	—
Faber & James† (54) 1921 ...	651 boys	,,	,,	89·4	92·8	94·5	97·3	99·2	100·9	102·4	104·1	105·9	107·6	110·1	112·2	115·3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* Figures are taken from author's chart, and are approximate.

† Age means given are smoothed values obtained by combining three consecutive years.

Table 6. *Summary of Mean Diastolic Pressures for different Ages as found by various Observers (Males).*

Author	Technique	Material	Posture	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26—30	31—35	36—40	41—45	46—50	51—55	56—60
	Auscultatory																															
Stone (24) 1913 ...	4th point	61 males	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	(under	40) —	—	—81—	—	—	—	—→	←—	—82—	(over	40)
Barach & Marks (29) 1914	4th point	312 males	?	—	—	—	—	—	—	—	—	—	—	—	←—	—	—	—	—	89·8	—	—	—	—	—→	—	—	—	—	—	—	—
	5th point	338 ,,	?	—	—	—	—	—	—	—	—	—	—	—	←—	—	—	—	—	[84·2]	—	—	—	—	—→	—		—		—		
Stone (55) 1917 ...	4th point	500 males	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—80—	—85—	(under	40) —	—	—	—	—	—→		—		
Sorapure* (17) 1918	,,	769 soldiers	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—	82	80	73	82	83	80	86	80	78·5	80	81·5	—	—	—	—
Kilgore (26) 1918 ...	,,	542 males	Lying	—	—	—	—	—	—	—	—	—	—	—	—	←—	—	—	—	81·5	(mean	age 20)	—	—	—	—	—→					
Bertrand-Smith (16) 1918	,,	400 aviation recruits	,,	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	←—	— (me	an age	24·2)—	—	84·1	—	—	—	—→	—			
Smythe (52) 1919 ...	,,	100 cadets	Sitting	—	—	—	—	—	—	—	—	—	—	—	—	—	—	←—80	·4 —→	←—	—	—87	·3 —	—	—→	84·0	86·7	89·5	—	—	—	—
Mackenzie (28) 1920	4th point	1835 males	?	—	—	—	—	—	—	—	—	—	—	—	←—	—	—	—	—	—85—	—	—	—	—	—	—→	←—	—88—	—→	←—	—91—	—→
	5th point	(Insurance data)	?	—	—	—	—	—	—	—	—	—	—	—	←—	—	—	—	—	[79]	—	—	—	—	—	—→	←—	[82]	—→	←—	[85]	—→
Lee (7) 1921 ...	4th point	662 male students	Sitting	—	—	—	—	—	—	—	—	—	—	—	(Avera	ge age	18)	80	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Faber & James† (51) 1921	,,	651 boys	,,	60·3	62·7	64·0	65·4	66·7	67·8	68·9	69·9	71·1	71·9	73·3	74·6	75·8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

N.B. Bracketed figures are those obtained by using the 5th point as criterion for diastolic pressure.
* Figures are taken from author's chart, and are approximate.
† Age means given are smoothed figures obtained by combining three consecutive years.

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(30) and others, which assumed a regular rise of systolic pressure throughout life, was insufficient. Thus, Faught gives the following rule for finding the normal pressure: "add 1 mm. to 120 for every 2 years above the age of 20"; and similar statements are to be found in most text-books (e.g. "add age in years to 100").

More recent work has proved definitely that such rules do not hold good; nevertheless they are being taught to medical students in this country at the present day. Thus Sorapure (17) in 1918 measured the systolic pressure of 769 Guardsmen in training at Hampstead, using the auscultatory method. His mean curve for ages 18—40 shows on the whole no rise between these ages, but on the contrary a maximum for 19—22 after which a slight fall occurs, and the pressure then remains almost level till 40. These observations were made at 4 p.m., immediately after a day's training, and are naturally somewhat higher throughout on this account (see Section (9) below).

In the same year Kilgore (26), from 314 young males (ages 16—35, but mostly 17—19), found an average of about 131 mm. in the recumbent posture, whilst Bertrand-Smith (16), working on 400 recruits of the American Aviation Service (average age 24·2, range 19—40), obtained a value 127·7, also in the recumbent posture. Using the auscultatory method and the sitting posture, Smythe (52) in 1919 made observations on 100 cadets, and we have extracted the following averages from his figures:

Age	No. of cases	Mean systolic pressure
18	8	121·2 mm.
19—21	8	127·1 „
22—25	14	126·0 „
26—30	34	123·9 „
31—35	22	125·1 „
36—40	14	125·3 „

Alvarez (46) in 1920 published results of systolic pressure measurements of 2930 male students in California, using the palpatory method and recumbent posture. The ages ranged from 16—25, and the mean curve shows a slight maximum at 17—18 (128 mm.) followed by a fall to 125·4 at 21, after which it remained at about 126 mm.

All these recent observations seem to agree in indicating that the systolic pressure tends to reach a maximum about the age of 19—20, and, after falling slightly, remains approximately level till the age of 40. This fact has not yet, so far as we are aware, been clearly pointed out; we shall refer to it again presently in considering our own results.

With regard to ages below 18, Faber and James (54) have recently published results of measurements on 651 American school boys, made with the same technique as our own (except that a 10 cm. cuff was used for most of the measurements instead of the standard 12 cm.). Their mean figures for the various ages have been obtained by a smoothing process combining three consecutive years to arrive at the mean value for

the middle year, and moreover more than one measurement was made on some of the children (1570 observations in all being included), so that it is not possible from their paper to arrive at the true age means for single measurements. The smoothed values (see Table 5) show however a fairly uniform rise from 89 mm. at age 4 to 115 mm. at age 16.

Present Data. In our series of measurements on males, the ages ranged from 5 to 40, and the actual distribution of systolic pressure with age is given in Table 7.

TABLE 7. *Distribution of Systolic Blood Pressure with Age (Males).*

Systolic Pressure* mm. of Hg	Central Ages																				25—29	30—34	35—39	Over 40 (Mean 49)	Totals
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24					
66— 69	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
70— 73	1	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3
74— 77	3	2	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7
78— 81	7	2	4	3	1	—	1	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	20
82— 85	7	1	3	6	8	4	—	1	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	34
86— 89	8	3	5	9	7	1	3	3	5	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	46
90— 93	7	2	7	5	14	9	6	13	3	1	1	—	1	—	—	—	—	—	—	—	—	—	—	—	69
94— 97	2	—	6	9	6	19	13	13	7	5	1	1	—	—	—	—	—	—	—	—	—	—	—	—	82
98—101	1	2	3	10	8	20	6	16	12	10	1	1	2	—	—	—	—	—	—	—	—	—	—	—	92
102—105	—	—	2	6	5	11	13	17	14	6	7	1	2	1	—	2	—	—	—	1	—	2	—	—	90
106—109	—	—	1	6	8	7	4	9	16	9	1	1	2	—	—	—	—	—	—	—	2	1	—	1	68
110—113	—	—	1	7	3	8	11	20	23	14	9	2	3	2	2	—	—	—	—	—	—	—	—	—	105
114—117	—	—	—	4	6	5	6	7	15	26	13	1	2	3	—	1	1	2	—	—	1	1	—	1	95
118—121	—	—	—	1	2	4	2	14	7	14	19	5	3	1	4	3	1	3	1	3	2	1	2	1	93
122—125	—	—	—	—	—	1	6	14	12	11	15	7	11	6	2	3	4	1	2	2	3	—	2	—	102
126—129	—	—	—	—	—	—	—	6	7	12	10	3	10	3	1	2	2	1	2	3	4	1	1	1	69
130—133	—	—	—	—	1	—	3	6	6	7	10	8	13	9	4	2	3	—	1	—	2	2	1	—	78
134—137	—	—	—	—	—	—	1	2	2	3	7	6	9	6	2	1	—	2	3	2	2	—	—	1	49
138—141	—	—	—	—	—	—	—	1	1	5	6	4	8	2	3	5	4	1	2	1	1	2	1	—	47
142—145	—	—	—	—	—	—	—	—	2	1	5	2	4	3	1	4	2	1	3	1	3	—	1	1	34
146—149	—	—	—	—	—	—	—	—	—	—	2	1	1	1	1	1	—	—	1	1	1	1	—	1	12
150—153	—	—	—	—	—	—	—	—	—	—	3	—	4	—	—	1	—	—	—	—	1	4	—	1	14
154—157	—	—	—	—	—	—	—	—	—	1	—	—	—	1	1	—	—	—	—	—	1	—	—	—	4
158—161	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	1	—	—	—	2
162—165	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	1	3
TOTALS	36	13	33	69	69	89	75	143	135	129	110	45	76	38	21	25	17	11	15	14	24	15	8	9	1219

* Readings being made to the nearest millimetre of mercury, the intervals are 65·5—69·5, 69·5—73·5, etc.

The numbers of cases, mean systolic pressures and standard deviations, with their probable errors, and the coefficients of variation at each age are given in Table 8. In each case the age interval is taken from half a year below to half a year above the age in question, e.g. mean for age 12 = mean for age group $11\frac{1}{2}$—$12\frac{1}{2}$ (an individual of age $12\frac{1}{2}$ exactly being counted as $\frac{1}{2}$ in the age 12 group and $\frac{1}{2}$ in the age 13 group).

The mean systolic pressures are plotted in Fig. 5 (p. 22), and it will be seen that the points from age 5 to 11 lie approximately on a straight line as do also the averages

from 19 to 37. We have therefore found it impossible to adequately represent the relation between systolic pressure and age by a single mathematical function.

Fitting by the method of least squares we have obtained the most satisfactory curve by means of two straight lines joined by a quintic curve which is continuous with and tangential to the former at ages 11 and 19. The equations of the resulting curve (drawn in Fig. 5) are as follows:

$A = 5$ to $11: P = 70{\cdot}07 + 3{\cdot}193A$,

$A = 11$ to $19: P = 1019{\cdot}98 - 271{\cdot}484A + 30{\cdot}6040A^2 - 1{\cdot}64268A^3 + {\cdot}04280A^4 - {\cdot}00044A^5$,

$A = 19$ to $37: P = 130{\cdot}95$,

where P = systolic pressure in millimetres, A = age in years.

TABLE 8. *Average Systolic Pressure at different Ages* (*Males*).

Central Ages	No. of cases	Mean Systolic Pressure	Standard Deviation	Coefficient of variation
		mm.	mm.	
5	36	85·27 ± ·82	7·27 ± ·58	8·53 ± ·68
6	13	85·33 ± 1·55	8·54 ± 1·13	10·00 ± 1·34
7	33	91·50 ± ·98	8·33 ± ·69	9·10 ± ·76
8	69	96·83 ± ·94	11·55 ± ·66	11·93 ± ·69
9	69	98·34 ± ·91	11·19 ± ·64	11·38 ± ·66
10	89	101·25 ± ·63	8·80 ± ·45	8·69 ± ·44
11	75	105·79 ± ·92	11·87 ± ·65	11·22 ± ·63
12	143	108·95 ± ·72	12·78 ± ·51	11·73 ± ·47
13	135	111·03 ± ·73	12·62 ± ·52	11·37 ± ·47
14	129	115·81 ± ·77	12·88 ± ·54	11·12 ± ·47
15	110	123·54 ± ·79	12·27 ± ·56	9·93 ± ·46
16	45	128·21 ± 1·35	13·42 ± ·95	10·47 ± ·75
17	76	129·03 ± 1·01	13·04 ± ·71	10·11 ± ·56
18	38	129·61 ± 1·15	10·55 ± ·82	8·14 ± ·63
19	21	130·36 ± 1·66	11·26 ± 1·17	8·64 ± ·91
20	25	131·02 ± 1·71	12·66 ± 1·21	9·66 ± ·93
21	17	130·79 ± 1·37	8·40 ± ·97	6·42 ± ·75
22—24	40	130·10 ± 1·09	10·23 ± ·77	7·86 ± ·60
25—29	24	132·00 }		
30—34	15	131·50 } 131·24 ± 1·41	14·30 ± 1·00	10·90 ± ·77
35—39	8	128·50 }		
Over 40 (Mean 49)	9	134·61 ± 3·89	17·28 ± 2·75	12·82 ± 2·07

This seems to indicate that whilst the rise of pressure up to age 11 is a simple function of increasing age, with the approach of puberty more complex influences come into play which govern the pressure growth until adolescence is complete at about 18. From age 19 onwards to 40 we find no conclusive evidence from our data of any significant change in pressure.

A reference to Table 5 shows that Judson and Nicholson's figures for American school boys show an increase from 92 mm. at age 5 to 106 at 14, whilst Faber and James' data, also for American boys, show an increase from 93 to 110. These increases of 14 and 17 mm. respectively are much less than we have found (30 mm.), the age averages being higher at the younger ages and considerably lower at the higher ages. The first mentioned observers made their observations in the recumbent posture.

Katzenberger found for German school children an increase of about 24 mm. between these ages, and his results are more in accord with our own, being however somewhat higher. Faber and James' method differed from our own in several important particulars, viz. (1) the first observations, if considered to be too high owing to the psychological effect of nervousness at the first test (see Section (11) below), were rejected, the

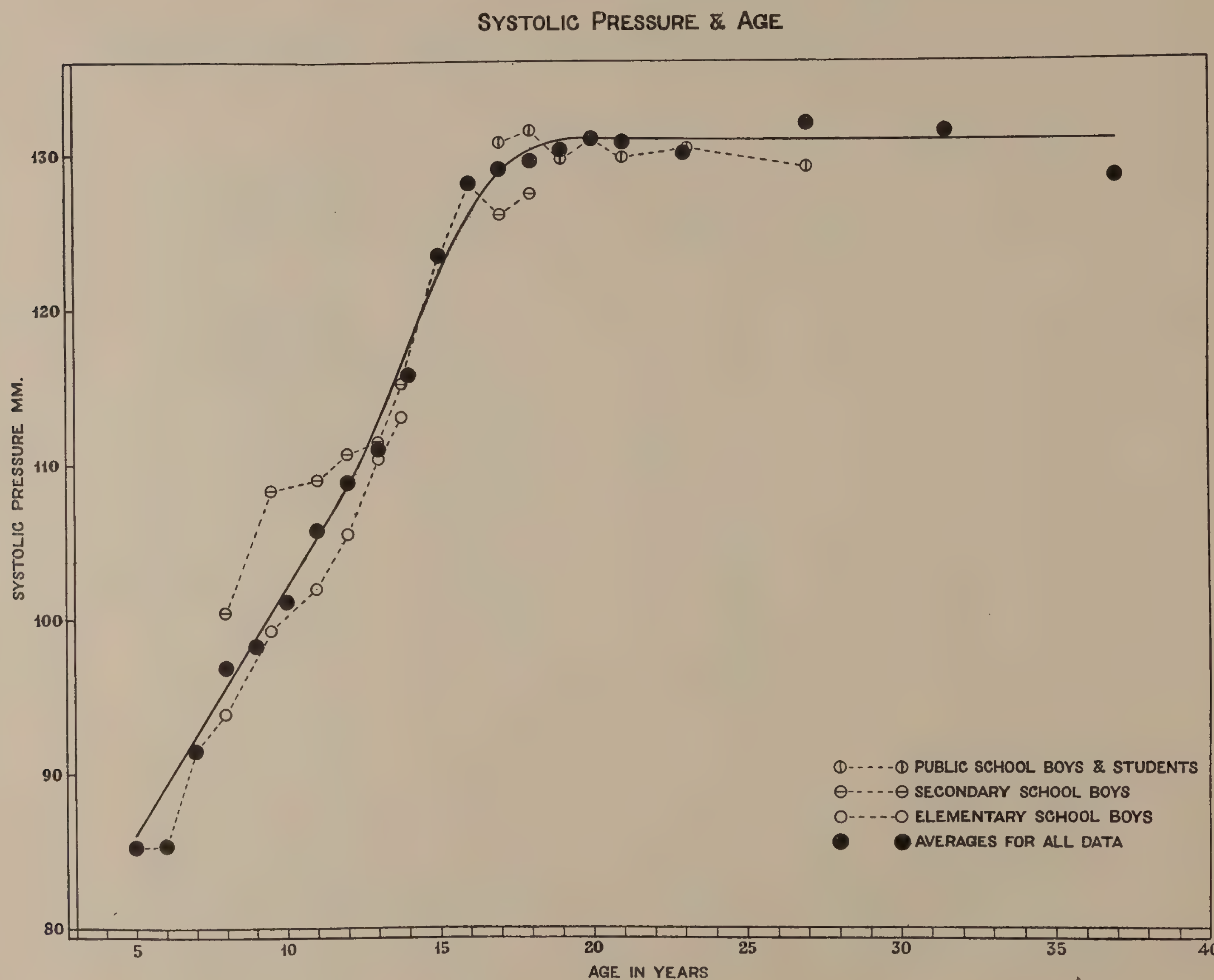


FIG. 5.

measurements being repeated until this effect was thought to have subsided; (2) several observations were made on a large number of the children, so that the means do not represent the means of first observations on different individuals; (3) about 15 °/ₒ of the children were taken from a School Clinic, and it seems highly probable that these

were below the average in physique. These facts in our opinion make their published results less useful for establishing normal averages, since in practice it is not usually possible to make a series of measurements on an individual, and eliminate any psychological effect there may be, before coming to a conclusion as to the normality or otherwise of the pressure found. We shall see later that the psychological effect can be fairly well allowed for by correcting the first reading for pulse rate: see Fig. 17 and Table 30.

Our averages for ages 13 and 14 lie somewhat below the age curve and it is possible that there is a real flattening of the pressure gradient in the years immediately preceding puberty. In our curve for Secondary School boys this is very marked (see Fig. 5), but we believe this to be partly accounted for by the higher social selection of boys in most Secondary Schools as we pass down the age scale below 12 years. Nevertheless, though the evidence is not conclusive, there is some indication of a state of relative inactivity preceding adolescence. The beginning of puberty on the contrary is marked by a steepening of the pressure gradient, so that in the 4 years from 13 to 17 the systolic pressure rises some 16 mm. Our age averages from 14 to 17 somewhat exaggerate this effect owing to the increasing selection of boys met with in most schools after the compulsory age is passed, and the fact that the Elementary Schools cease to figure in the data after 14. We believe this source of error to have been as far as possible eliminated in the smoothed curve; thus it will be noted that the 17 and 18 averages, which include a large percentage of Public School boys, lie somewhat above the curve.

Such an acceleration in growth during adolescence is also noticed in the curve of body weight, but this is not the whole explanation since a reference to Fig. 18 shows that the systolic pressure curves for boys of constant weight still show an increase in gradient during adolescence, indicating that during this period some additional factors are at work tending to raise the pressure. There can be little doubt that one of these factors is the passing into the circulation of "pressor" substances secreted by the various glands which commence to function actively about the time of puberty. Thus the adrenal glands are known to secrete into the blood a substance which stimulates the circulation and raises blood pressure, and it is probable that increased function of the thyroid and sexual glands has a similar effect. The rate of physical growth and most of the physiological processes are abnormally stimulated during this period, so that it is not surprising that the same phenomenon is found in connection with arterial pressure. We shall see presently that the component parts of the maximum pressure are affected at this period to a very different degree and in a different way, as a glance at Figs. 6 and 7 will show.

Turning next to ages from 19 onwards, we see from Table 8 and Fig. 5 that, apart from accidental variations due to the small number of cases, the mean systolic pressure shows little change from 19 to 39, the tendency being possibly to fall somewhat after 30. This result, though contrary to the statements in most text-books, is supported by the more recent observations which we have referred to. The actual mean values for this period show moderate agreement with those of recent workers using

the same technique; thus Smythe's data give a mean pressure of about 126 mm., whilst a series of measurements on cadets and officers of the Air Force (quoted by Greenwood and Newbold in a paper read to the Society of Biometricians) gave for cadets (90, average age 18·7) a mean systolic pressure 128·5 mm., for officers (267, average age 23·6) 129·6 mm., and for civilians (56, average age 24·8) 130·2 mm.

Our mean value for 152 British adult males under 40 is 131 mm.

Variability in normal persons. It has long been noticed that the systolic pressure may have very different values in a series of normal persons of the same age, but until recently the range of pressures which could be considered as normal was somewhat arbitrarily fixed. Thus Woley (47) concluded from observations on 1000 cases that a range from 100—145 mm. might be taken as limits of normality at ages from 15 to 40; Mackenzie (28) thinks a total range of 26 mm. at each age may be considered normal for purposes of life-insurance work, and Fisher (51) considers an excess of 12 mm. above the age average to be safe for the same purpose; Oliver (40) speaks of a variation of ± 15 mm. as the range to be expected amongst normal individuals.

Sorapure (17) found from his series of soldiers ranges up to 70 mm. for some age groups, but the variation was probably exaggerated by the fact that these observations were made at the end of an arduous day of physical training.

Barach and Marks (29), grouping their observations on young males into 10 mm. pressure intervals, obtained a distribution which we find to yield a standard deviation of 14 mm. Kilgore (26) also gives in his paper the distribution in 5 mm. intervals of systolic pressure readings on 314 males (ages 16—36), both by palpatory and auscultatory methods, and we find these distributions to give standard deviations of 11·1 mm. (palpatory) and 10·2 mm. (auscultatory). Alvarez (46) in 1920 pointed out that the frequency distribution of his readings for systolic pressure of 2930 male students in California (ages 16—40) approximated closely to the theoretical probability curve constructed on the basis of his standard deviation of 14·9 mm. for the whole series. Faber and James (54) in 1921 worked out a similar comparison for a group of boys aged 9—11, and found a fair agreement also with the theoretical curve, but owing to the method of selection of the readings which we have referred to, they obtained much lower values for their standard deviations, averaging about 7 mm. for each age group from 5 to 16 and giving a coefficient of variation about 6·5 °/ₒ.

The *standard deviations* at different ages obtained from our series are given in Table 8 and vary from 9—14 mm., showing no consistent change with age from 8 to 40. The value of σ for the whole distribution as it stands is 17·49 mm.

The coefficient of variation is from 8 to 12 °/ₒ, being highest during growth and lower from age 18 onwards. The total frequency distribution of deviations from the smoothed age averages is shown graphically in Fig. 8. A normal frequency curve has been fitted to this distribution, the value of σ being 11·69 mm. and the coefficient of goodness of fit ·046 (i.e. the chance is about 1 in 20 that such a distribution would be met with through pure chance).

Considering that a smoothed age curve has been used for the corrections, such a coefficient is perhaps not worse than might be expected. Moreover the actual distri-

bution (see Table 17) is somewhat skew in form, the mean-square deviation below average being 11·26 and above average 12·08. If we suppose the limits of normality to be represented by deviations of ± 3 times the standard deviation from the age curve we should theoretically expect 2·8 cases per 1000 to lie outside these limits. Actually in 1219 cases we find 3 cases with deviations from the age curve greater than 3σ, so that we have no reason to suppose that these cases were of necessity pathological. Any cases with definite signs or symptoms of heart disease or pathological conditions of the circulation were primarily excluded from all our tables, and will be mentioned in the last section; 4 out of 13 of these heart cases gave systolic readings outside the limits referred to.

TABLE 9. *Probable Limits of Normality in Blood-pressure Readings (auscultatory) at various Ages, no account being taken of Physical Development and Pulse Rate*.*

Central Ages	Outside these limits pressures are almost certainly pathological		Outside these limits pressures should be regarded as open to suspicion	
	Systolic	Diastolic	Systolic	Diastolic
	mm.	mm.	mm.	mm.
7	59—128	34— 86	71—116	42— 77
8	62—131	35— 85	73—119	43— 78
9	66—135	36— 88	77—122	44— 79
10	69—138	38— 90	80—126	46— 81
11	72—141	40— 92	83—129	48— 83
12	75—144	42— 94	86—132	51— 85
13	80—149	45— 97	91—136	54— 88
14	84—153	47— 99	95—141	56— 90
15	89—158	49—101	100—146	58— 92
16	93—162	51—103	104—150	59— 94
17	95—165	52—104	107—152	60— 95
18	97—166	54—106	108—154	63— 97
19	98—167	57—109	109—155	65—100
20—24		59—111		67—102
25—29		58—110		68—101
30—40		55—107		65— 98

* When the weight and pulse rate are known Tables 30 and 31 should be used.

For clinical purposes, if the age of an individual alone is taken into account, we should suggest that if the systolic pressure is found to deviate from the age curve by more than three times the mean-square deviation, it should be considered definitely abnormal; and moreover that any reading persistently deviating from the age curve by more than twice the mean-square deviation should be considered as suspicious even in the absence of any signs or symptoms. We have tabulated these limits for ages 7—40 in Table 9, but more useful limits may be obtained by correcting also for the weight and pulse rate of the individual. (See Sections (5), (6), Figs. 17, 18 and Table 30.)

The danger of laying down limits of normality for age groups apart from such correction is demonstrated by the fact that we find no less than 15 °/。 of our boys to

give pressure readings above the limits of normality prescribed by Faber and James, probably because our boys were of better average physique.

(ii) *Diastolic Pressure.*

Previous Work. We have collected in Table 6 (see folding sheet facing p. 19) the principal data of other workers showing the average diastolic pressure at various ages. Earlier work in which the oscillatory method was used has been omitted, as the results are not of much value for comparison with others.

For ages up to 17 the only useful comparative data are those of Faber and James (54). A comparison of their mean values at various ages with our figures in Table 11 shows

TABLE 10. *Distribution of Diastolic Blood Pressure with Age (Males).*

Diastolic Blood Pressure* mm. of Hg	Age: Centred at																		Age: 25—29	Age: 30—34	Age: 35—39	Age: Over 40 (Mean 49)	Totals
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24					
40— 43	2	2	1	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
44— 47	—	2	2	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
48— 51	5	4	5	5	1	1	1	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	24
52— 55	6	14	9	8	7	9	6	4	4	1	1	—	—	—	—	—	—	—	—	—	1	—	70
56— 59	2	3	8	6	5	5	4	2	2	—	1	—	—	—	—	—	—	—	—	—	—	—	38
60— 63	10	20	18	22	17	29	21	12	12	3	4	2	1	1	—	—	—	—	—	—	—	—	172
64— 67	—	11	4	10	12	14	26	17	7	3	6	1	1	—	—	—	—	—	—	1	—	1	114
68— 71	4	5	9	17	9	32	19	22	16	6	9	7	1	1	—	1	—	—	1	1	1	—	161
72— 75	—	3	4	6	13	14	25	24	18	10	16	7	2	3	—	1	—	3	4	3	1	1	158
76— 79	1	—	1	1	2	6	10	13	9	6	7	5	2	1	2	1	2	3	1	2	1	1	77
80— 83	—	—	4	1	1	9	14	18	17	8	17	8	2	3	6	4	5	2	7	3	3	1	133
84— 87	—	—	—	—	—	4	3	3	7	4	3	4	4	6	—	2	3	2	3	1	—	2	51
88— 91	—	—	—	—	1	2	4	6	3	4	8	2	2	5	6	1	1	3	3	1	—	—	52
92— 95	—	—	1	—	—	—	—	2	8	—	4	2	2	3	2	—	2	1	4	1	1	2	35
96— 99	—	—	—	—	—	—	—	—	2	—	—	—	2	1	1	—	1	—	—	—	—	—	7
100—103	—	—	—	—	—	—	—	1	—	—	—	—	2	1	—	1	1	—	1	1	—	1	9
Totals	30	64	66	77	69	126	133	124	107	45	76	38	21	25	17	11	15	14	24	14	8	9	1113

* Readings being taken to the nearest millimetre of mercury, the intervals are 39·5—43·5, 43·5—47·5, etc.

that as regards the diastolic pressure there is close agreement at ages 14 to 16, but their averages are higher than ours for younger boys. From 18 to 35 the most useful data are those of Sorapure (17), and the chart of age means given by this author for soldiers under training shows no constant change from 18 to 35, the average pressure being approximately 80 mm. for this period. Smythe's (52) results for 100 cadets yield rather higher values, but the conditions under which the measurements were taken were different; they show a considerable rise from about 18 to 21, a slight fall to 27 and a tendency to rise again towards 40.

Barach and Marks' (29) results for 312 males we find to give a mean value 89·8 mm. for ages 15—25.

Stone's (55) observations on 500 adult males under 40 gave 80—85 mm.; Kilgore's (26)

distribution of diastolic pressures of 542 males (ages 16—35) we find to give a mean value 81·5 mm.; Bertrand-Smith (16) from 400 recruits of the American Aviation Service (average age 24·2, range 19—40) obtained a mean diastolic pressure 84·1 mm.; Lee (7) from 662 students of Harvard University (average age 18) obtained a mean value 80 mm.; Mackenzie's statistics for the Prudential Assurance Co. of America (28) give a mean of 85 mm. for ages 15—30, and 88 mm. from 30—40; whilst a series of measurements on cadets and officers of the Air Force, for which means were given by Greenwood and Newbold, shows values from 80 to 81 mm. The actual age distributions are not given in any of these papers.

TABLE 11. *Average Diastolic Pressure at different Ages (Males).*

Central Ages	No. of cases	Mean diastolic pressure	Standard deviation	Coefficient of variation
		mm.	mm.	
7	30	57·90 ± 1·01	8·20 ± ·71	14·16 ± 1·26
8	64	59·56 ± ·62	7·32 ± ·44	12·29 ± ·74
9	66	62·23 ± ·81	9·78 ± ·57	15·72 ± ·95
10	77	63·06 ± ·56	7·26 ± ·39	11·51 ± ·63
11	69	65·15 ± ·64	7·85 ± ·45	12·05 ± ·70
12	126	67·72 ± ·52	8·66 ± ·37	12·79 ± ·55
13	133	69·80 ± ·49	8·45 ± ·35	12·11 ± ·51
14	124	72·82 ± ·54	8·97 ± ·38	12·32 ± ·54
15	107	74·32 ± ·71	10·95 ± ·51	14·73 ± ·69
16	45	75·63 ± ·83	8·25 ± ·59	10·91 ± ·78
17	76	76·66 ± ·70	9·02 ± ·49	11·77 ± ·65
18	38	77·29 ± ·86	7·86 ± ·61	10·17 ± ·79
19	21	84·17 ± 1·63	11·07 ± 1·15	13·15 ± 1·39
20	25	84·54 ± 1·20	8·92 ± ·85	10·55 ± 1·02
21—24	57	84·52 ± ·62	6·98 ± ·44	8·26 ± ·53
25—29	24	83·83 }		
30—34	14	80·36 } 81·50 ± ·83	8·32 ± ·58	10·21 ± ·73
35—39	8	76·50 }		
Over 40 (Mean 49)	9	84·17 ± 2·36	10·50 ± 1·67	12·48 ± 2·01

Present Data. The age distribution of diastolic pressures in our series of males is shown in Table 10, and the means, standard deviations and coefficients of variation for each age in Table 11. The relation to age is also shown in Fig. 6. It has again proved impossible to fit a single mathematical function to the whole range of ages owing to the remarkable change in the form of the curve between 16 and 20. We have therefore fitted a series of three curves which are continuous and tangential to each other at $16\frac{1}{2}$ and $20\frac{1}{2}$. The formulae for the curve are:

$$A = 7 \text{ to } 16{\cdot}5:\ P = 90{\cdot}67 - 10{\cdot}688A + 1{\cdot}0925A^2 - {\cdot}03009A^3,$$

$$A = 16{\cdot}5 \text{ to } 20{\cdot}5:\ P = 1190{\cdot}08 - 186{\cdot}841A + 10{\cdot}3312A^2 - {\cdot}18772A^3,$$

$$A = 20{\cdot}5 \text{ to } 39:\ P = 68{\cdot}28 + 1{\cdot}492A - {\cdot}0347A^2,$$

where P = diastolic pressure in mm., A = age in years.

We found it very difficult to read the diastolic pressure in young children below 7 years, and concluded that little reliance could be placed on these observations; we have therefore only included the diastolic pressure measurements from age 7 upwards. There is evidently a continuous rise of pressure in childhood, which becomes less rapid during the first part of adolescence, but this is followed by a rapid rise to adult level about the end of adolescence. From 24 to 37 there seems to be a gradual fall in pressure.

DIASTOLIC PRESSURE & AGE

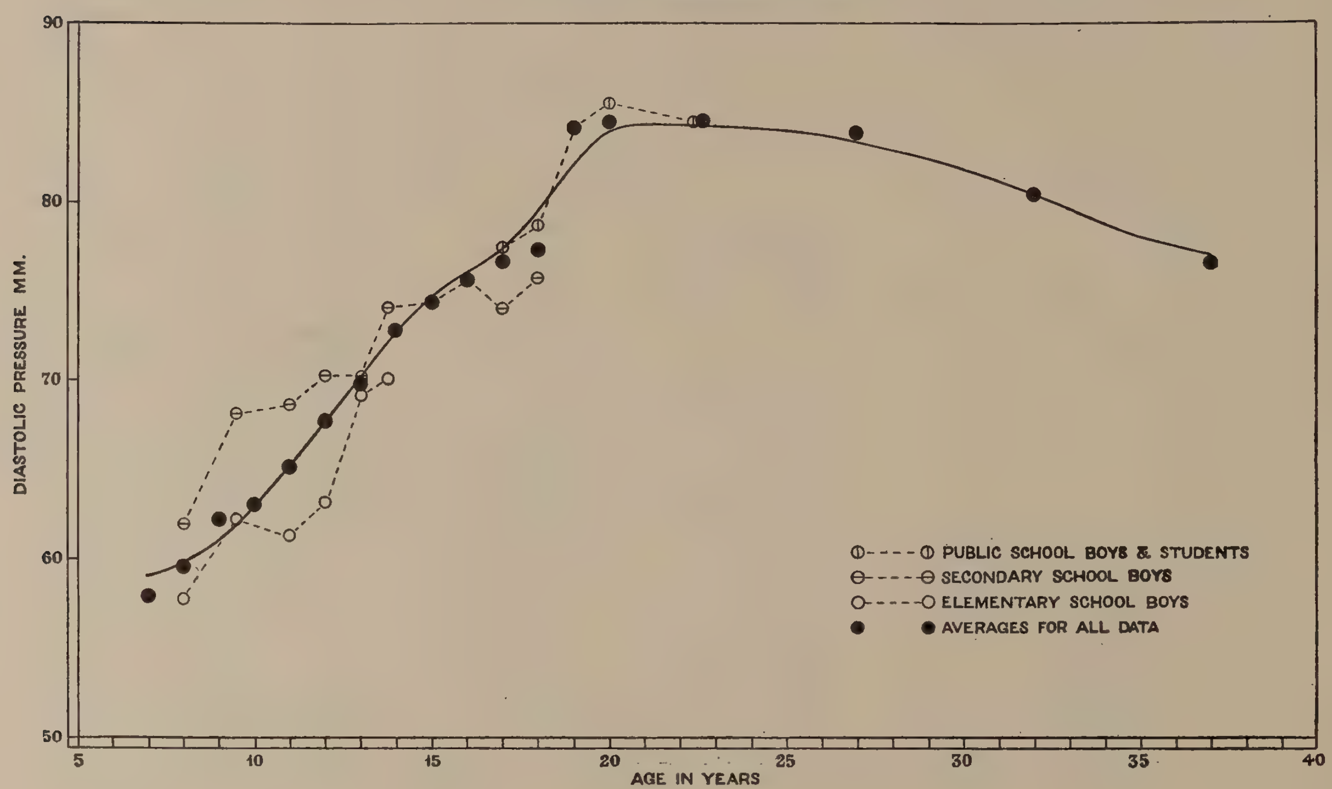


FIG. 6.

A sudden rise in diastolic pressure between 18 and 21 is also indicated in Smythe's cases, quoted above, which showed a difference of 8·5 mm. between the averages for 18—20 and 21—25; his data also agree in indicating a slight fall after 25.

Sorapure's data commence at 18, and since he was dealing with Army recruits, most of this age group were probably over 18½ and would correspond to our "19" group. They agree with ours in showing a maximum between 21 and 24 (the value at 20 is probably an error) and a slightly lower pressure between 25 and 35. His general averages are a few millimetres lower than our values for College Students, but all his cases were in good physical training.

Since the diastolic pressure is largely a measure of the peripheral resistance of the arterial system to the passage of blood through it, we should naturally expect this "residual" pressure to be lowered by continual physical exercise, and on the contrary

to be raised by a sedentary habit of life. It seems possible that the rise which we find from 18 to 20 years of age is rather exaggerated by the fact that we are here passing from boys in the upper forms of Secondary Schools and of a large Public School where physical training and outdoor games are practised to a considerable degree, to the beginning of University life in a city, where the tendency is often to drop athletics almost completely. It is probable that the continuance of an athletic habit of life keeps the diastolic pressure at a lower level (see Section (9)). There is no doubt that manual workers also tend to have a lower diastolic pressure than sedentary workers for the same reason; this is confirmed by our scanty data for factory workers (see Table 23).

Although this factor may be partly responsible for the large difference in the age means for 18 and 19, it is evident that for sedentary workers at any rate—and they comprise a large section of the population—a considerable rise, such as we have indicated in the smoothed curve, occurs about this period. Moreover it is clear from a comparison of the age curves that *the final rise of diastolic pressure to the early adult level lags several years behind that of the systolic pressure, and takes place principally after the period of adolescence is over.* The onset of adolescence seems rather to retard than to accelerate the rise of diastolic pressure, and the curves for constant height in Fig. 20 are almost horizontal from 13 to 17, indicating that the increase in height during this period is sufficient to account for the diastolic gradient.

Variability. The diastolic pressure shows considerable variation in normal persons; thus Oliver (46) speaks in his book of a variation of 5—7 mm. from the average as being common, whilst MacWilliam and Melvin (21) speak of a range of 15 mm. as being within normal limits. The distributions given by Barach and Marks (29), arranged in 10 mm. intervals for some 300 males (ages 15—25), we find to yield standard deviations of 10·6 mm. (5th point measurements) and 11·8 mm. (4th point). Mackenzie (28), from Life Insurance statistics, concludes that for Insurance purposes a range of 12 mm. might be considered as normal, and considers that a pressure less than 60 mm. or more than 103 mm. is abnormal at any age, by whatever technique the readings are taken. Stone (24), from measurements of 500 males under 40 for whom he found an average diastolic pressure of 80—85 mm., concluded that a persistent level over 100 mm. indicated a mild degree of hypertension, which was usually pathological if over 100 mm., and indicated definite arterial disease if over 115 mm. Faber and James (54) obtained standard deviations for various ages, which for boys amounted to 5—7 mm. about the age means; the method of selection of readings used by these observers no doubt accounted for the smaller dispersions they obtained; if we attempt to apply their tables indicating the "limits of normality" to our own results, we find that as many as 7·3 % of our cases would have to be considered as pathological.

The *standard deviations* of our data at each age are given in Table 11. They vary from 7 to 11 mm. and show no consistent change between the ages of 7—40. For the whole distribution of Table 10, $\sigma = 11{\cdot}44$ mm. The coefficient of variation lies between 10 and 14 %. The dispersion about the age curve is shown in Table 17 and Fig. 8; the S.D. is reduced to 8·82 mm., and the coefficient of goodness of fit is

·001. The mean-square deviation above average is 9·04 and below average 8·59. Actually 3 cases out of 1113 gave readings outside the limits $\pm 3\sigma$, as might be theoretically expected in a normal distribution.

We shall show in Sections (5), (6) that the variation can be somewhat narrowed by correcting for height and pulse rate, but we have given in Table 9 approximate limits on the basis of ranges $\pm 3\sigma$ and $\pm 2\sigma$ about the age averages, which may be of use for clinical purposes when it is not practicable to apply Table 31.

(iii) *Pulse Pressure.*

Previous Work. The "pulse pressure," or extra pressure developed during each systole in the artery under examination, has not received much attention until recently.

Stone (24) found the average pulse pressure of 35 normal males under 40 years of age to be 39 mm., and for 26 over 40 to be 41 mm. Barach and Marks (29) gave a distribution of pulse pressures in 317 males (ages 15—30), which we find to give a mean value of 44·7 mm. Bertrand-Smith (16) obtained a mean pulse pressure of

TABLE 12. *Comparative Data for average Pulse Pressure at different Ages* (*Males*)

Author	No. of cases	Ages 4 to 16	18	19—20	21—25	26—30	31—35
Faber and James (54)	651 boys	Regular increase from 30 to 40 mm.					
Smythe (52)	100 cadets	—	←——	—44·7→	36·6	40·5	38·4
Sorapure (17)* ...	769 soldiers	—	50	56	51·5	50	48·5

* Figures taken from chart, and approximate only.

42·2 mm. for 400 recruits of the American Aviation Service (average age 24, range 19—39), these observations being made in the recumbent posture. Kilgore's (26) figures give a much higher value for ages 17—19, the mean of 720 measurements in the recumbent position, as we calculate from his total percentage distribution, being 52 mm. (range of age said to be 16—36, but chiefly 17—19).

From Life Insurance statistics in America, Mackenzie (28) found an average of 37 mm. for 1578 males (ages 15 to 45). The only comparable data for individual ages are from the observations of Smythe, Sorapure and Faber and James, and we have summarized their results in Table 12. The averages given from Sorapure's material have been extracted from his chart, and are approximate; they are unusually high for reasons that we have indicated in dealing with the systolic pressure. We have also commented on Faber and James' smoothed averages, which are lower than our own, especially for ages approaching 16.

Present Data. The distribution of pulse pressure with age in our own series is shown in Table 13, and the means, standard deviations and coefficients of variation are given in Table 14.

TABLE 13. *Distribution of Pulse Pressure with Age (Males).*

AGE

Pulse Pressure* mm. of Hg	Centred at 7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25—29	30—34	35—39	Over 40 (Mean 49)	Totals
15— 18	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
19— 22	1	—	—	1	1	—	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7
23— 26	3	5	3	5	1	5	9	5	1	1	2	—	—	1	—	—	—	—	—	—	—	—	41
27— 30	7	9	12	6	4	15	15	7	4	2	2	—	1	1	—	—	—	1	—	1	—	1	88
31— 34	5	13	14	15	11	11	11	9	5	2	4	1	1	3	3	1	1	—	1	3	—	1	115
35— 38	5	12	17	12	15	25	24	21	8	2	3	2	3	2	2	3	1	3	2	—	1	—	163
39— 42	5	6	10	12	10	11	14	19	11	3	12	5	3	4	4	1	2	—	9	—	—	3	144
43— 46	3	9	1	13	11	11	19	12	12	4	3	7	5	3	3	4	4	3	1	2	2	1	133
47— 50	1	6	5	3	4	19	12	18	18	7	14	7	2	1	1	—	2	3	4	1	1	—	129
51— 54	—	3	2	4	4	11	6	7	18	6	5	2	1	5	1	—	1	1	2	1	1	1	82
55— 58	—	1	1	1	6	4	7	12	10	3	7	4	1	1	—	1	1	1	3	2	1	—	67
59— 62	—	—	1	4	—	8	4	6	3	5	7	1	—	1	2	—	3	2	—	2	1	—	50
63— 66	—	—	—	1	1	3	5	3	6	6	5	3	3	—	1	1	—	—	—	1	—	—	39
67— 70	—	—	—	—	—	3	2	2	5	—	4	3	—	2	—	—	—	—	—	1	—	1	23
71— 74	—	—	—	—	—	—	—	—	2	2	3	3	1	1	—	—	—	—	—	—	1	—	13
75— 78	—	—	—	—	1	—	2	1	2	—	2	—	—	—	—	—	—	—	1	—	—	—	9
79— 82	—	—	—	—	—	—	—	—	2	1	2	—	—	—	—	—	—	—	1	—	—	—	6
83— 86	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
87— 90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
91— 94	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	1
95— 98	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
99—102	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
103—106	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
Totals	30	64	66	77	69	126	133	124	107	45	76	38	21	25	17	11	15	14	24	14	8	9	1113

* Readings being taken to the nearest mm. of mercury, the intervals are 14·5—18·5, 18·5—22·5, etc.

TABLE 14. *Average Pulse Pressure at different Ages (Males).*

Central Ages	No. of cases	Mean Pulse pressure	Standard deviation	Coefficient of variation
		mm.	mm.	
7	30	$34{\cdot}10 \pm {\cdot}85$	$6{\cdot}88 \pm {\cdot}60$	$20{\cdot}18 \pm 1{\cdot}83$
8	64	$37{\cdot}31 \pm {\cdot}67$	$7{\cdot}98 \pm {\cdot}48$	$21{\cdot}39 \pm 1{\cdot}33$
9	66	$36{\cdot}44 \pm {\cdot}63$	$7{\cdot}56 \pm {\cdot}44$	$20{\cdot}75 \pm 1{\cdot}27$
10	77	$39{\cdot}25 \pm {\cdot}73$	$9{\cdot}45 \pm {\cdot}51$	$24{\cdot}08 \pm 1{\cdot}38$
11	69	$41{\cdot}20 \pm {\cdot}79$	$9{\cdot}68 \pm {\cdot}56$	$23{\cdot}50 \pm 1{\cdot}42$
12	126	$42{\cdot}56 \pm {\cdot}66$	$10{\cdot}95 \pm {\cdot}47$	$25{\cdot}73 \pm 1{\cdot}16$
13	133	$41{\cdot}37 \pm {\cdot}60$	$11{\cdot}90 \pm {\cdot}49$	$28{\cdot}76 \pm 1{\cdot}29$
14	124	$43{\cdot}63 \pm {\cdot}67$	$11{\cdot}08 \pm {\cdot}47$	$25{\cdot}40 \pm 1{\cdot}16$
15	107	$49{\cdot}77 \pm {\cdot}77$	$11{\cdot}78 \pm {\cdot}54$	$23{\cdot}67 \pm 1{\cdot}15$
16	45	$52{\cdot}50 \pm 1{\cdot}46$	$14{\cdot}54 \pm 1{\cdot}03$	$27{\cdot}70 \pm 2{\cdot}12$
17	76	$51{\cdot}92 \pm 1{\cdot}09$	$14{\cdot}02 \pm {\cdot}77$	$27{\cdot}00 \pm 1{\cdot}58$
18	38	$51{\cdot}76 \pm 1{\cdot}21$	$11{\cdot}06 \pm {\cdot}86$	$21{\cdot}37 \pm 1{\cdot}73$
19	21	$46{\cdot}98 \pm 1{\cdot}67$	$11{\cdot}35 \pm 1{\cdot}18$	$24{\cdot}16 \pm 2{\cdot}66$
20	25	$46{\cdot}26 \pm 1{\cdot}67$	$12{\cdot}40 \pm 1{\cdot}18$	$26{\cdot}81 \pm 2{\cdot}74$
21	17	$44{\cdot}26 \pm 1{\cdot}58$	$9{\cdot}68 \pm 1{\cdot}12$	$21{\cdot}87 \pm 2{\cdot}65$
22—24	40	$46{\cdot}10 \pm {\cdot}95$	$8{\cdot}95 \pm {\cdot}67$	$19{\cdot}41 \pm 1{\cdot}52$
25—29	24	$47{\cdot}50 \pm 1{\cdot}57$		
30—34	14	$48{\cdot}79 \pm 2{\cdot}29$	$11{\cdot}77 \pm {\cdot}83$	$24{\cdot}18 \pm 1{\cdot}80$
35—39	8	$52{\cdot}00 \pm 2{\cdot}51$		
Over 40 (Mean 49)	9	$49{\cdot}39 \pm 4{\cdot}47$	$19{\cdot}90 \pm 3{\cdot}16$	$40{\cdot}29 \pm 7{\cdot}37$

In Fig. 7 the average pulse pressures are plotted for each age, and present a gradually increasing gradient from 7 to the beginning of adolescence, the mean value at 14 being 43 mm. During adolescence a remarkable accentuation of pulse pressure occurs, reaching a maximum height of about 52 mm. at 17—18 (a value identical with Kilgore's average for this age). This is followed by a quick fall to about 45 mm. at age 21, from which age onwards the original upward gradient is resumed. It is obviously impossible to represent these changes by a single function, but we have

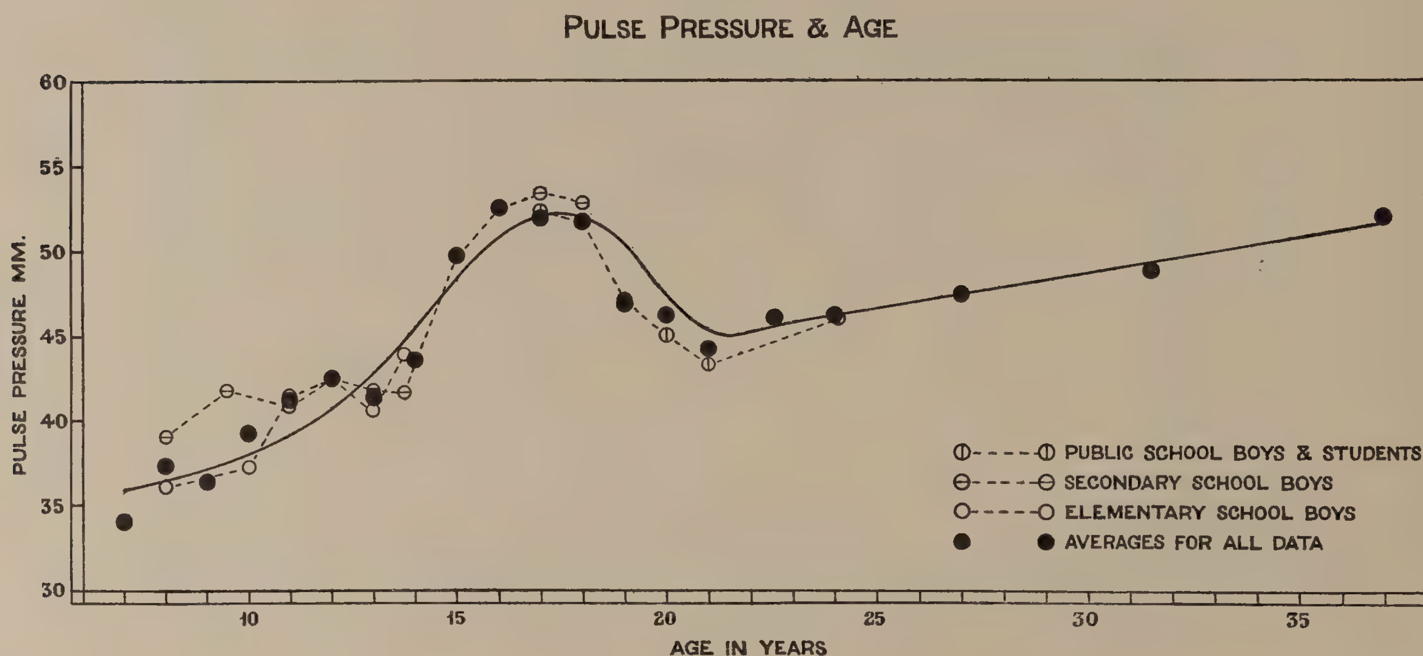


FIG. 7.

obtained the continuous curve of Fig. 7 by fitting to the points a series of curves continuous and tangential to each other at ages 15, 19½ and 21½. The formulae are:

$$A = 9 \text{ to } 15: \; P = 48{\cdot}62 - 3{\cdot}144A + {\cdot}2081A^2,$$

$$A = 15 \text{ to } 19{\cdot}5: \; P = -55{\cdot}22 + 6{\cdot}072A + {\cdot}3637A^2 - {\cdot}02057A^3,$$

$$A = 19{\cdot}5 \text{ to } 21{\cdot}5: \; P = -1785{\cdot}27 + 290{\cdot}953A - 15{\cdot}2060A^2 + {\cdot}26200A^3,$$

$$A = 21{\cdot}5 \text{ to } 37: \; P = 36{\cdot}00 + {\cdot}423A,$$

where P = pulse pressure in mm., A = age in years.

The curious form of the curve from 14 to 19 is connected with the simultaneous steepening of the systolic gradient and flattening of the diastolic and *vice versâ* which we have already commented on; thus the systolic curve has almost reached its maximum when the diastolic is beginning to rise more sharply. These facts lead to the interesting conclusion that *between the ages of* 15 *and* 19 *the heart is producing at every beat a greater head of pressure in the arterial system than at any other period before middle life.* About the years 16 to 18 this head of pressure averages apparently

DISTRIBUTION OF PRESSURE DEVIATIONS FROM AGE CURVES

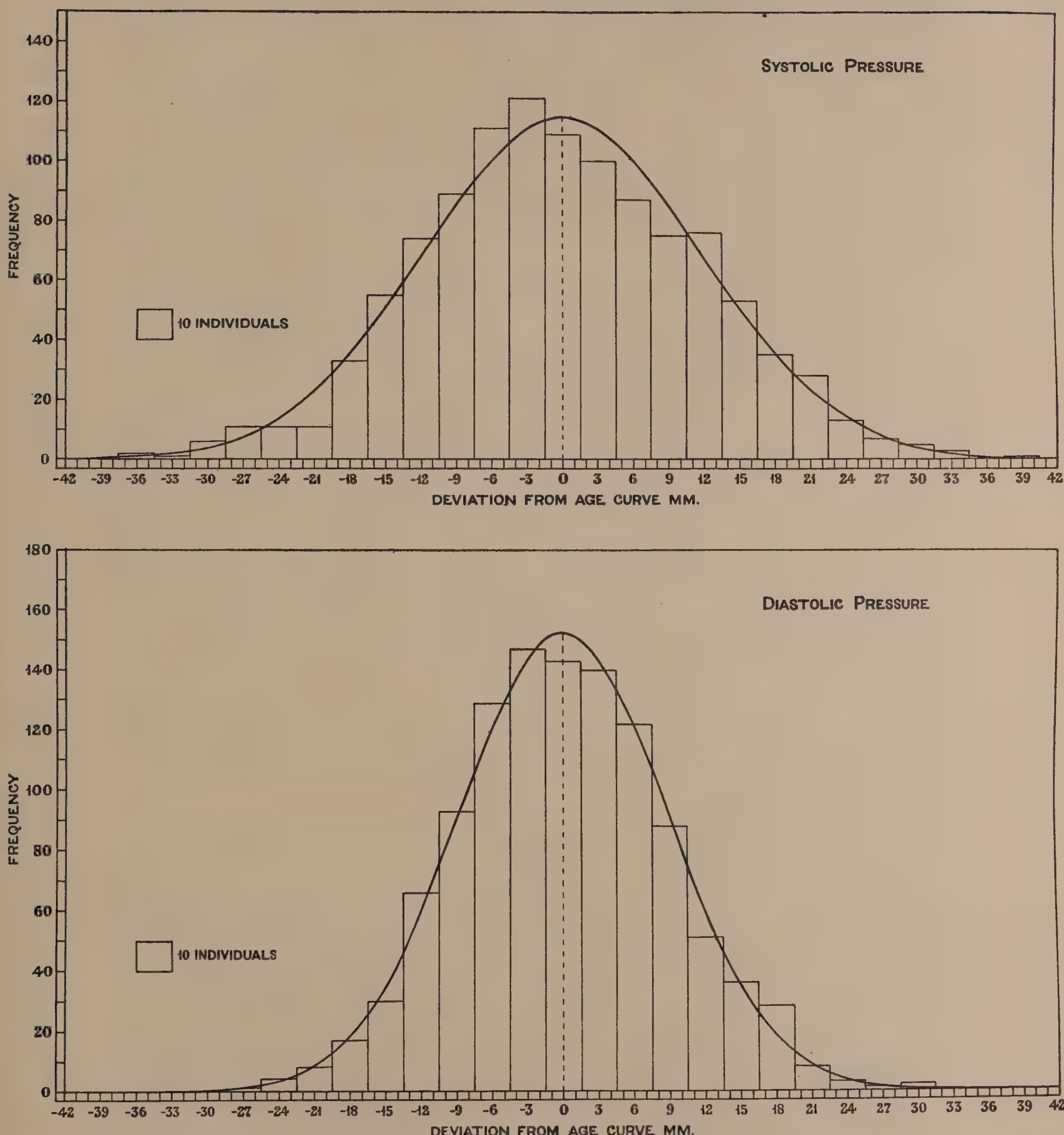


FIG. 8.

nearly 20 °/。 higher than the general average for young adults and it seems probable that this is connected with the fact that the rate of physical growth also reaches a maximum about 16, so that the need for an efficient circulation is also at its greatest.

We shall discuss this further in considering the "cardiac output," but it may be well to mention that Sorapure's curves for soldiers under physical training show a maximum pulse pressure to be reached rather later (19—20), followed by a somewhat abrupt fall, though this was not, we believe, pointed out in the author's paper. This fact is not incompatible with the explanation we have suggested, since we should expect that the abnormal additional strain of intensive physical training commencing about the 18th year would result in maintaining the high level of pulse pressure and delaying the fall till rather later.

Variability. The range of normal variation of pulse pressure is seen from Tables 13, 14 to be very great; the S.D. increases to a maximum of about 14 mm. at 16—17 and again falls, the coefficient of variation averaging about 25 °/。 throughout. Between 16 and 18 we must conclude that pulse pressures as high as 90 mm. cannot be considered as of necessity pathological, nor can values as low as 25 mm. One boy of 16 was found to have a pulse pressure of 103 mm. without any definite signs of cardiac or arterial disease, and we observed two others aged 16 and 17 with pulse pressures between 85 and 90 mm. without signs of disease. [Three boys with aortic incompetence, aged 14, 15 and 16, gave pulse pressures of 92, 83, 97 mm. respectively; one boy with mitral and a suspicion of aortic disease, had a pulse pressure 100 mm., whilst a boy with mitral regurgitation gave as low a value as 20 mm.; these cases are of course not included in our tables.] The upper limits for normal pulse pressure prescribed by Faber and James rise from 50 mm. at age 4 to 60 mm. at age 16, but they are much too low from age 12 onwards. It is evident that the variation in pulse pressure is so great during the period of adolescence that it cannot be of great diagnostic value at this time of life. After 20, however, the standard deviation becomes somewhat less, and we would suggest 25 mm. and 80 mm. as the probable lower and upper limits of normality between 20 and 40, whilst any value above 70 mm. should be regarded with suspicion during this period.

(iv) *Pressure Ratios.*

A good deal has been written about the usefulness of various blood-pressure ratios for purposes of diagnosis. To Goodman and Howell's (14) ratio involving the lengths of the individual phases of sound heard by the auscultatory method we have already briefly referred, but in our experience the defining of the 2nd phase is often so difficult that we do not consider this ratio to be of great practical value except as an indication of the competency of the heart's action in certain cases of valvular disease. Sorapure (17) considered from his study of soldiers that the presence of definite 2nd and 3rd phases was characteristic of a "fit" man, but that they were frequently absent in "unfit" men. Our criticism of this conclusion would be that his observations on fit men were all made immediately after hard physical training, whilst his unfit men were presumably not undergoing training of the same severity, and that it is the severity of the exercise rather than the "fitness" which brings out the phases more clearly. In

our own experience the 2nd phase was certainly best defined as a rule in the more athletic adolescents, and was usually indefinite in younger boys or students who were not taking part in athletics at the time. We should doubt, however, whether its definiteness or otherwise was an index of fitness apart from this, or whether it was constant enough to be relied upon from any point of view.

Tiegerstadt, following Strassburger, proposed to measure cardiac efficiency by the quotient

$$\frac{\text{arterial flow per minute}}{\text{work of heart per minute}} = \frac{\text{pulse pressure} \times \text{rate}}{\text{systolic pressure} \times \text{rate}} = \frac{\text{pulse pressure}}{\text{systolic pressure}},$$

and maintained that this ratio should be normally 30—35 °/₀; we are not however convinced of the validity of the reasoning by which the ratio is arrived at.

Stone (24) (55) proposed the ratio pulse pressure/diastolic pressure as an index of the "heart-load," and concluded that normally an additional pressure 50 % in excess of the diastolic level has to be developed by the heart in systole before the aortic valves open and the flow is maintained. This ratio seems to us to be of more value than that of Strassburger, since it expresses the ratio of kinetic energy expended by the heart in moving the blood column, to the potential energy of the arterial system at the moment before the heart begins to contract. Cadbury (56), Dana (44) and Faught (57) have attempted to demonstrate the usefulness of this ratio in dealing with pathological cases as a guide both to prognosis and treatment. Stone's statement, however, that the normal limits of this ratio are 40—60 % certainly does not hold good for young adults (see below). Sorapure found that the average value of this ratio was 60 % in his series of soldiers, whilst Bertrand-Smith found an average of 50·2 % from 400 young males, and Barach and Marks' (29) distribution for 400 males (aged 15—25) gives a mean value 55·5 %.

The effect of age on this ratio has not been studied in detail, and we have therefore worked out the distribution of the inverted ratio $\left(\frac{D.P}{P.P}\right)$ at various ages from our cases, in Table 15, and the resultant means are given in Table 16.

The average ratio remains fairly constant at about 1·6 to 1·7 up to the age of 14; it then falls to a minimum of 1·5 during adolescence and again rises to an average adult value approximating to 1·8. This adult value approximates to Stone's normal average ratio of pulse pressure to diastolic of 50 %, but even for adults the range of normal variation of this ratio is evidently considerably greater than he maintains. Thus a range of 40 % to 60 % corresponds in our table to 1·66—2·50, and it can be seen from the distribution that no less than 44 % of our cases aged 20 and over lie outside these limits. During the period of adolescence the variability in the ratio is even greater, the coefficient of variation for the period 15—18 being as high as 31 % as against 25 % for adults aged 20—24, and 21 % for adults of 25—39. The fall in the coefficient of variation with advancing age gives us a clue to the reason why Stone's conclusion that his ratio was rarely widely different from 50 % in normal persons has been refuted by later observations. Thus Barach and Marks from 400 males aged 15—25 found a range of values for this ratio extending from 10 % to 140 % (which distribution we find gives a coefficient of variation of 43 %), and Kilgore found

a similar wide range for adolescents, from 20 °/ₒ to 160 °/ₒ (the coefficient of variation of their distribution we also find to be over 30 °/ₒ). It appears from our figures that the ratio of diastolic pressure to pulse pressure before the age of 25 is so widely

TABLE 15. *Distribution of Blood Pressure Ratio with Age (Males).*

Ratio of Diastolic Pressure to Pulse Pressure	Age: Centred at 7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25—29	30—34	34—39	Over 39 (Mean 49)	Totals
·455* — ·655	—	—	—	—	—	—	—	—	2	1	—	—	—	—	—	—	—	—	—	—	—	—	3
— ·855	—	—	—	3	2	2	3	1	3	—	3	—	—	1	—	—	—	—	—	—	1	1	20
—1·055	1	1	2	5	1	11	9	7	10	4	10	4	2	—	—	—	—	—	—	—	—	—	67
—1·255	5	8	8	9	9	10	13	10	15	11	11	3	3	2	1	—	—	1	—	2	—	1	122
—1·455	5	12	7	11	11	21	17	22	17	6	9	7	—	2	2	1	2	1	—	4	2	—	159
—1·655	2	14	10	8	13	20	14	17	19	8	12	5	3	4	1	1	2	3	4	1	1	—	162
—1·855	5	13	14	13	11	14	20	18	11	3	10	9	1	4	1	—	3	2	4	1	1	1	159
—2·055	5	4	3	16	9	16	16	13	14	7	5	5	5	3	4	2	1	3	6	1	2	—	140
—2·255	3	5	12	3	6	13	9	11	7	—	2	3	2	1	3	2	5	—	7	2	1	2	99
—2·455	2	4	5	1	2	8	10	10	4	3	3	3	1	2	3	1	—	1	1	2	—	1	67
—2·655	2	2	4	2	2	4	6	5	1	1	5	—	1	3	2	—	—	1	—	1	—	2	44
—2·855	—	—	—	1	1	3	5	3	1	—	3	—	3	2	—	1	—	1	—	—	—	1	25
—3·055	—	—	—	3	1	4	4	4	1	—	1	—	—	—	—	—	—	1	—	—	—	—	19
—3·255	—	—	—	2	—	—	2	2	—	—	1	—	—	—	—	—	1	—	—	—	—	—	8
—3·455	—	—	1	—	—	—	1	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	4
—3·655	—	—	—	—	—	—	1	—	1	—	—	—	—	1	—	—	—	—	—	—	—	—	3
—3·855	—	—	—	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
—4·055	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
Totals	30	63	66	77	69	126	131	124	107	45	75	39	21	25	17	8	14	14	22	14	8	9	1104

* Here —1·055, for example, signifies ·855 to 1·055.

TABLE 16. *Ratio of Diastolic to Pulse Pressure at Various Ages (Males).*

Age centre	No. of cases	Mean Ratio	S.D.	Ratio from smoothed age curves*	Age Group	No. of cases	Mean Ratio	S.D.	Ratio from smoothed age curves*
7	30	1·72 ± ·05	·44	1·64	15	107	1·58 ± ·03	·53	1·54
8	63	1·65 ± ·03	·37	1·63	16	45	1·55 ± ·05	·51	1·50
9	66	1·79 ± ·04	·47	1·64	17	75	1·62 ± ·04	·57	1·49
10	77	1·70 ± ·04	·55	1·66	18	39	1·63 ± ·04	·39	1·53
11	69	1·70 ± ·04	·50	1·66	19	21	1·86 ± ·08	·56	1·63
12	126	1·72 ± ·03	·51	1·66	20—24	78	1·96 ± ·04	·51	1·85
13	131	1·82 ± ·04	·62	1·64	25—39	44	1·81 ± ·04	·38	
14	124	1·80 ± ·03	·56	1·60					

* I.e. ratio of mean D.P. to mean P.P.

variable (any value from ·5 to 4 being possible during adolescence, or any value from 1 to 3 in young manhood) that it can be of little use for diagnosis; but that after 25 the range of variation probably narrows down, and it is possible that Stone's contention may be justified in later life.

The explanation would seem to be that *after cessation of growth and establishment of a more balanced circulation, the normal requirements are met by a ratio of diastolic to pulse pressure approximating to 2, but that until this balance has been reached, no useful conclusion can be drawn from the value of this ratio in any individual.*

(v) *Correlation between Systolic, Diastolic and Pulse Pressures.*

The problem of pressure ratios may be attacked in another way by finding what correlations exist between the pressure components.

TABLE 17. *Correlation between Systolic and Diastolic Pressures (Deviations corrected for Age).* 1117 *Males aged* 7—39.

Diastolic Pressure*		Systolic Pressure*: No. of mm. below age curve													No. of mm. above age curve													Totals
		35—37	32—34	29—31	26—28	23—25	20—22	17—19	14—16	11—13	8—10	5—7	2—4	+1 to −1	2—4	5—7	8—10	11—13	14—16	17—19	20—22	23—25	26—28	29—31	32—34	35—37	38—40	
No. of mm. below age curve	26—28	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	1
	23—25	—	—	—	—	—	—	—	—	—	—	—	1	—	1	2	—	—	—	—	—	—	—	—	—	—	—	4
	20—22	—	—	—	—	—	1	1	—	—	2	3	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	8
	17—19	—	—	—	1	—	—	2	2	1	1	—	2	2	3	—	—	1	—	—	—	2	—	—	—	—	—	17
	14—16	—	—	—	3	2	—	4	5	3	1	3	4	2	2	1	—	—	—	—	—	—	—	—	—	—	—	30
	11—13	1	1	3	1	5	1	3	7	7	9	6	3	5	3	2	4	4	—	1	—	—	—	—	—	—	—	66
	8—10	1	—	2	—	2	2	6	11	14	10	12	10	6	3	3	5	5	1	—	—	—	—	—	—	—	—	93
	5—7	—	—	1	2	1	2	4	9	14	12	16	12	18	9	2	9	4	7	4	3	—	—	—	—	—	—	129
	2—4	—	—	—	3	1	3	5	7	11	18	18	18	14	12	11	12	4	5	1	1	2	—	1	—	—	—	147
	+1 to −1	—	—	—	1	—	1	3	8	14	11	19	20	14	12	11	7	7	9	2	1	2	—	—	1	—	—	143
No. of mm. above age curve	2—4	—	—	—	—	—	—	3	3	6	12	15	22	15	16	13	3	12	5	9	6	—	—	—	—	—	—	140
	5—7	—	—	—	—	—	1	1	3	2	9	13	13	14	16	17	9	7	8	5	2	1	—	1	—	—	—	122
	8—10	—	—	—	—	—	—	1	—	2	3	4	8	10	11	10	9	11	7	3	4	—	3	1	1	—	—	88
	11—13	—	—	—	—	—	—	—	—	—	1	2	3	5	4	9	4	7	6	2	3	2	1	1	1	—	—	51
	14—16	—	—	—	—	—	—	—	—	—	—	—	3	3	6	5	8	3	—	2	2	2	1	—	—	—	1	36
	17—29	—	—	—	—	—	—	—	—	—	—	—	2	1	—	1	2	8	4	4	4	1	—	1	—	—	—	28
	20—22	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	3	—	1	1	1	—	—	—	—	—	8
	23—25	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1	1	—	—	—	—	—	—	—	3
	26—28	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1
	29—32	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1	—	—	—	—	—	—	2
Totals		2	1	6	11	11	11	33	55	74	89	111	121	109	100	87	75	76	53	35	28	13	7	5	3	—	1	1117

* Intervals are 1·5—4·5, 4·5—7·5, etc.

The correlation tables for the pairs of the three variables are shown in Tables 17—19 (the deviations from the smoothed age averages being used in order to correct for age). The corrected correlation coefficients obtained from these tables are as follows:

Systolic and diastolic pressures $r = \cdot 4662$.
Systolic and pulse pressures $r = \cdot 6795$.
Diastolic and pulse pressures $r = -\cdot 2692$.

If we attempt to express these results in words, we may say that in any large group of young males of the same age, we shall find that those having systolic pressures above the average for that age will tend to have both diastolic and pulse pressures above the average; that those with diastolic pressures above average will tend to have pulse pressures below average but not by the same amount, so that

TABLE 18. *Correlation between Systolic and Pulse Pressures (Deviations corrected for Age). 1117 Males aged 7—39.*

SYSTOLIC PRESSURE*

Pulse Pressure*	No. of mm. below age curve													No. of mm. above age curve													Totals
	35—37	32—34	29—31	26—28	23—25	20—22	17—19	14—16	11—13	8—10	5—7	2—4	+1 to −1	2—4	5—7	8—10	11—13	14—16	17—19	20—22	23—25	26—28	29—31	32—34	35—37	38—40	
No. of mm. below age curve 29—31	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
26—28	—	—	1	1	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	4
23—25	1	—	—	3	1	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	6
20—22	—	1	2	2	1	1	2	2	2	2	1	2	—	1	—	—	1	—	—	—	—	—	—	—	—	—	20
17—19	—	—	2	—	1	3	4	5	4	2	5	2	1	—	—	—	—	—	—	—	—	—	—	—	—	—	29
14—16	—	—	—	2	5	1	2	5	4	5	5	6	4	4	—	—	—	—	—	—	—	—	—	—	—	—	44
11—13	—	—	1	—	3	1	7	11	16	11	11	7	6	4	2	2	1	—	—	—	—	—	—	—	—	—	83
8—10	—	—	—	2	—	3	6	8	11	18	15	11	8	4	4	2	1	1	1	1	—	—	—	—	—	—	96
5— 7	—	—	—	—	—	—	4	12	16	18	21	23	15	11	14	4	14	—	1	—	—	—	—	—	—	—	153
2— 4	—	—	—	—	—	—	6	5	9	10	15	20	11	18	14	8	—	3	2	—	—	—	—	—	—	—	121
+1 to −1	—	—	—	—	—	1	—	4	5	9	17	16	19	14	11	6	9	2	2	2	1	—	—	—	—	—	118
No. of mm. above age curve 2— 4	—	—	—	—	—	—	—	2	4	8	9	11	15	12	14	6	10	7	1	4	1	1	—	—	—	—	105
5— 7	—	—	—	—	—	—	—	1	1	2	8	13	17	10	10	9	7	7	2	4	2	—	—	—	—	—	93
8—10	—	—	—	—	—	—	—	—	1	2	—	4	6	9	7	4	10	8	6	1	1	1	—	—	—	—	60
11—13	—	—	—	—	—	—	—	—	—	2	1	3	2	3	2	14	5	6	6	3	1	1	1	—	—	—	50
14—16	—	—	—	—	—	—	—	—	—	—	3	1	4	3	5	11	4	9	4	1	—	2	1	—	—	—	48
17—19	—	—	—	—	—	—	—	—	—	—	—	—	1	2	2	3	5	6	4	5	2	1	—	—	—	—	31
20—22	—	—	—	—	—	—	—	—	—	—	—	2	—	3	1	3	5	3	2	2	1	—	1	1	—	—	24
23—25	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	2	3	1	2	—	1	1	—	1	—	1	13
26—28	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	3	2	—	—	1	—	—	8
29—31	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	1	1	—	1	—	—	—	—	—	—	—	5
32—34	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1	—	—	—	2
35—37	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
38—40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	2
41—43	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
44—46	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
47—49	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50—52	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
Totals	2	1	6	11	11	11	33	55	74	89	111	121	109	100	87	75	76	53	35	28	13	7	5	3	—	1	1117

* Intervals are 1·5—4·5, 4·5—7·5, etc.

the total (systolic) pressures will tend to be above the average also. One of the conclusions to be drawn from this is that, in addition to age, there are other factors responsible for producing individual pressure variations, which tend to influence both pressure components in the same sense.

Some of these factors, as we shall see, are *weight*, *height* and *pulse rate*, which are positively related to both systolic and diastolic pressures.

Probably another of these factors is *heredity*, and such cases of hereditary hypertension as we have met with have shown supernormal values both for diastolic and systolic pressures concurrently.

The higher correlation between systolic and pulse pressures may be explained by the fact that the latter is the most variable component of the systolic pressure, since it

TABLE 19. *Correlation between Diastolic and Pulse Pressures (Deviations corrected for Age)*

1117 *Males aged* 7—39.

DIASTOLIC PRESSURE*

PULSE PRESSURE*		No. of mm. below age curve										No. of mm. above age curve										TOTALS
		26—28	23—25	20—22	17—19	14—16	11—13	8—10	5—7	2—4	+1 to −1	2—4	5—7	8—10	11—13	14—16	17—19	20—22	23—25	26—28	29—31	
No. of mm. below age curve	29—31	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	1
	26—28	—	—	—	—	—	—	—	1	1	—	—	1	1	—	—	—	—	—	—	—	4
	23—25	—	—	—	—	—	1	—	1	2	—	—	1	1	—	—	—	—	—	—	—	6
	20—22	—	—	—	—	—	2	3	3	—	1	2	1	3	1	1	2	1	—	—	—	20
	17—19	—	—	—	—	—	2	1	2	2	3	7	3	4	1	2	2	—	—	—	—	29
	14—16	—	—	—	—	1	4	3	2	4	6	3	7	4	5	5	—	—	—	—	—	44
	11—13	—	—	—	—	1	3	5	4	12	15	11	15	6	4	4	—	2	—	—	1	83
	8—10	—	—	—	2	2	2	5	7	17	13	14	12	5	6	4	4	—	1	1	1	96
	5— 7	—	—	—	1	2	6	13	17	16	23	20	16	15	6	10	7	1	—	—	—	153
	2— 4	—	—	—	1	4	6	9	13	17	15	17	19	9	5	2	2	1	1	—	—	121
	+1 to −1	—	—	1	1	4	7	8	16	17	14	15	13	9	7	1	3	2	—	—	—	118
No. of mm. above age curve	2— 4	—	—	—	1	3	6	13	10	18	13	13	8	10	5	—	4	—	1	—	—	105
	5— 7	—	—	1	1	2	7	12	18	10	11	7	7	8	3	3	2	1	—	—	—	93
	8—10	—	—	1	1	2	3	4	9	7	4	9	10	5	2	2	1	—	—	—	—	60
	11—13	—	—	1	1	2	3	3	4	10	7	8	4	2	4	—	1	—	—	—	—	50
	14—16	—	1	2	2	2	4	4	7	6	9	6	2	2	—	1	—	—	—	—	—	48
	17—19	—	—	—	2	2	2	2	6	3	3	6	2	2	1	—	—	—	—	—	—	31
	20—22	—	1	1	1	2	3	6	4	2	1	1	—	1	1	—	—	—	—	—	—	24
	23—25	—	—	—	—	1	3	2	2	—	2	1	—	1	—	1	—	—	—	—	—	13
	26—28	—	1	—	—	—	1	—	2	2	1	—	1	—	—	—	—	—	—	—	—	8
	29—31	1	1	—	1	—	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	5
	32—34	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	2
	35—37	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	38—40	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
	41—43	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	44—46	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	47—49	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	50—52	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
TOTALS		1	4	8	17	30	66	93	129	147	143	140	122	88	51	36	28	8	3	1	2	1117

* Intervals are 1·5—4·5, 4·5—7·5, etc.

adjusts itself from moment to moment to every physical or psychological call upon the organism, and the total pressure is naturally most highly correlated with its most variable component. The considerable negative correlation between diastolic and pulse pressures may be partly due to the fact that the diastolic is more difficult to measure with accuracy than the systolic, and every error of measurement of the former in

excess of the latter will naturally help to make the correlation with pulse pressure more negative. For the rest, it indicates that the higher the minimal or initial pressure preceding each contraction of the ventricle, the less additional force is necessary to keep the blood in motion.

In order to determine the form of the regressions of one pressure variable on another, we have plotted in Fig. 9 the mean deviations (corrected for age) of each

REGRESSION OF COMPONENTS ON TOTAL PRESSURE

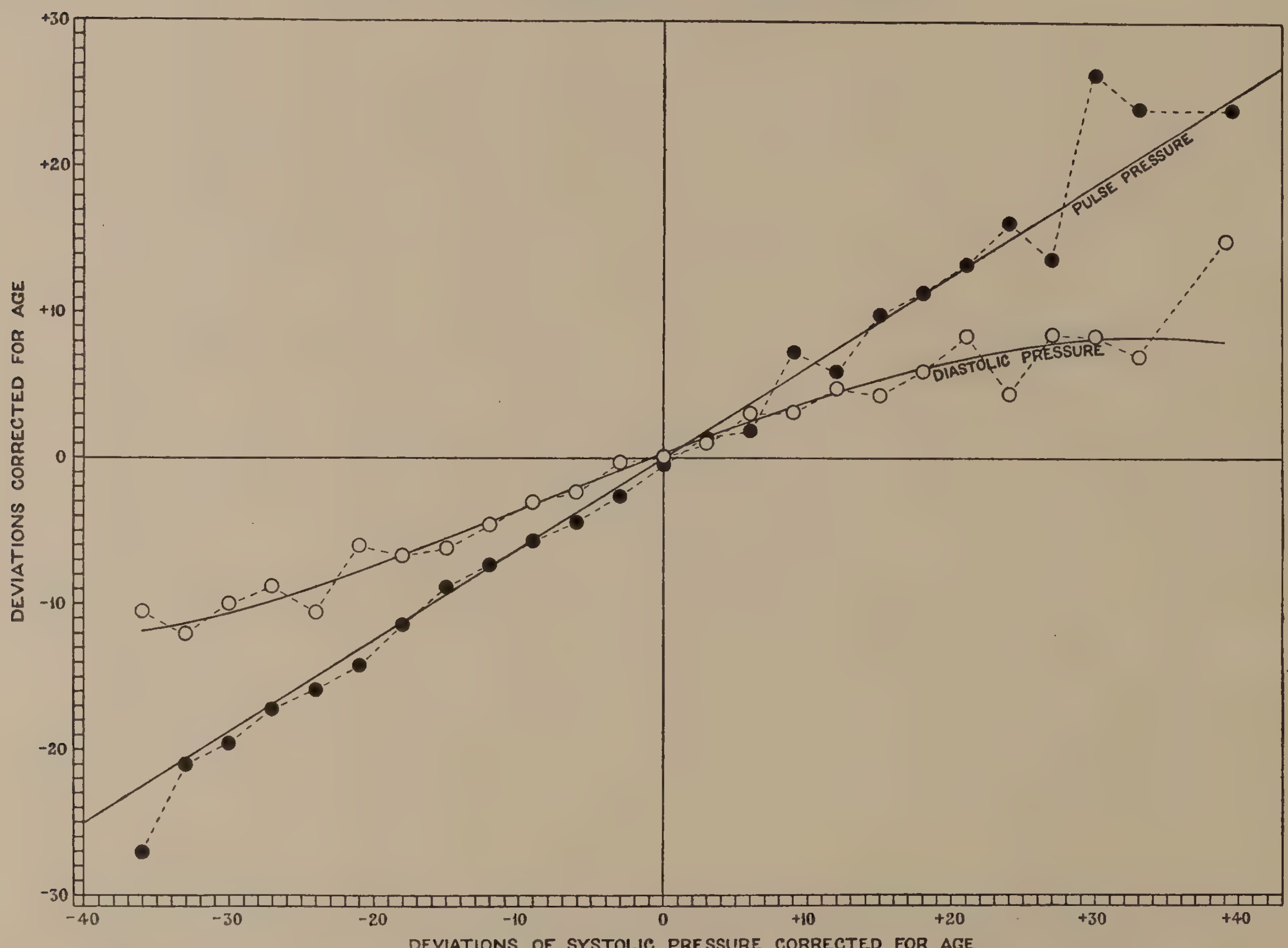


FIG. 9.

component of systolic pressure, corresponding to increasing deviations of the latter from the normal. The zero lines therefore represent average pressure for the age in question. Both these regression curves approximate to straight lines until the systolic deviations become very large; hence the ratio of the components tends to remain constant for moderate systolic deviations. When systolic pressure becomes far removed from the average, however, the ratio of diastolic to pulse pressure deviation tends to

fall appreciably. The regression curve of diastolic pressure, corrected for age, on systolic pressure, corrected for age, is the cubic

$$y = \cdot 26 + \cdot 3806x - \cdot 001595x^2 - \cdot 00007737x^3,$$

where y and x are deviations from average pressures. This does not sensibly depart from the straight line $y = \cdot 26 + \cdot 38x$ for values of x under about 25 mm.

The regression curve of pulse pressure on systolic has been represented in Fig. 9 by the straight line

$$y + \cdot 319 = \cdot 638x,$$

but strictly speaking the cubic

$$y + \cdot 26 = \cdot 6194x + \cdot 001595x^2 + \cdot 00007737x^3$$

would be in better agreement with the diastolic regression curve, since the sum of the two component deviations should be equal to the total deviation (x) for all values of the latter. This cubic, however, approximates closely to the straight line till high values of x are reached, when the data become too scanty to be able to say which of these is the more correct.

In Fig. 10 we have likewise shown the corrected deviations in systolic and pulse pressures, for increasing deviations in diastolic pressure. The regression curves here are only approximately rectilinear for small deviations in diastolic pressure. When the latter becomes moderately subnormal the systolic pressure tends to return towards the average, whilst the upward trend of pulse pressure becomes more exaggerated for diastolic deficiencies exceeding about 15 mm. This is difficult of explanation; it might indicate that these very subnormal diastolic readings were really errors of measurement due to absence of the 4th auscultatory point, but this is not supported by the distribution in Fig. 8 which appears homogeneous; it seems more likely that very low diastolic pressures tend to be compensated for by unusually large pulse pressures. For positive deviations of diastolic pressure the regression curves do not show such evident departure from the rectilinear form.

The curve of regression of pulse pressure (corrected for age) on diastolic (corrected for age) is best given by the hyperbola shown in Fig. 10:

$$y = -14 \cdot 72 - 1 \cdot 1780x + \cdot 9265\sqrt{(x + 15 \cdot 0829)^2 + 2 \cdot 3705},$$

obtained by taking as asymptotes lines parallel to

$y + 2 \cdot 10x + 27 \cdot 11 = 0$ (best fitting line from $x = -27$ to $x = -15$),

and $y + \cdot 25x + \cdot 61 = 0$ (,, ,, ,, ,, $x = -12$ to $x = +30$).

The regression curve of systolic, corrected, on diastolic, corrected, has been represented in Fig. 10 by the cubic

$$y = -\cdot 62 + \cdot 7479x + \cdot 00884x^2 - \cdot 0006193x^3.$$

Owing to the necessary relation between the components the difference between the y's in the two curves should however always equal x; the hyperbola

$$y = -14 \cdot 72 - \cdot 1780x + \cdot 9265\sqrt{(x + 15 \cdot 0829)^2 + 2 \cdot 3705}$$

would fulfil this condition and possibly give a better representation of the regression of systolic on diastolic pressure.

(5) Pulse Rate.

We have already had cause to refer to the interdependence of blood pressure and pulse rate in discussing the reactions which occur on changes of posture.

Since one method of increasing the head of pressure from a pump is to increase the number of strokes per minute (within certain limits), we should expect from purely mechanical principles to find that in a given individual, a rise in pulse rate would be usually accompanied by a rise in pulse pressure, and therefore of systolic

REGRESSION OF SYSTOLIC & PULSE PRESSURES ON DIASTOLIC PRESSURE

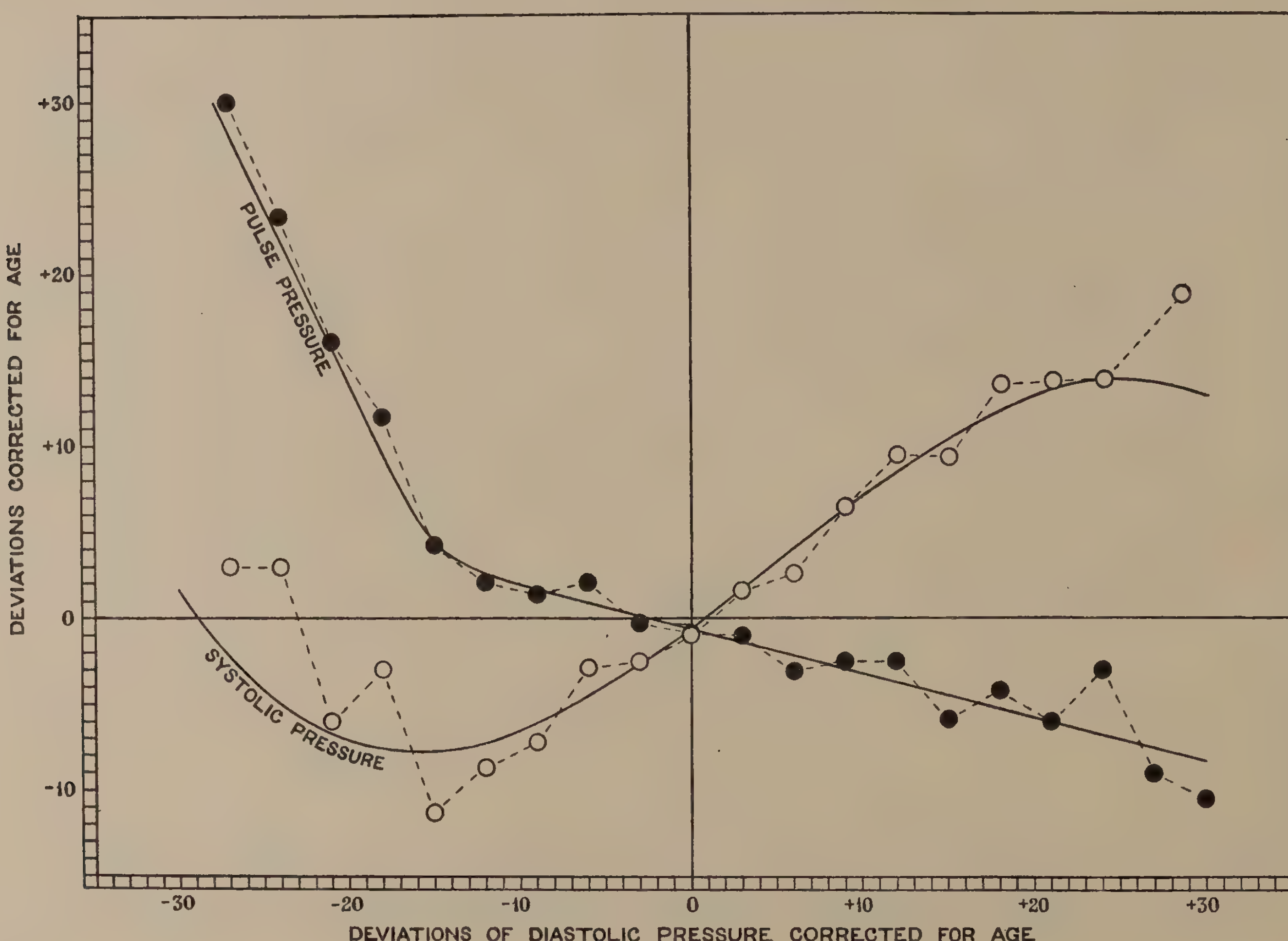


Fig. 10.

pressure. As a matter of fact this is usually the case, and such transient factors as excitement, physical exertion, the taking of food, and time of day generally cause concurrent variations in pulse rate and blood pressure.

Thus Thorne (58), from observations on a few individuals under treatment, concluded that a slowing of the pulse rate may be accompanied by a fall in systolic pressure, rather than by a compensatory rise.

Wheelon (34) in 1921, by experiments on 66 students, demonstrated that the average systolic and diastolic pressures, and the pulse rates all increased concurrently in passing through the series—recumbent, sitting, standing, five minutes running—average systolic increased 23 mm., pulse rate 52 per minute.

It does not necessarily follow, however, that individuals with constitutionally higher pulse rates will also tend to have constitutionally higher blood pressures. This can only be determined by finding the correlation between pulse rate and pressure in a large number of persons after correcting for all transient factors likely to influence the heart's action. The only attempt to establish a relationship of this kind is, as far

TABLE 20. *Distribution of Pulse Rate with Age (Males).*

	Age																								
Pulse Rate* per minute	Centred at																				25—29	30—34	35—39	Over 40 (Mean 49)	Totals
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24					
47— 50	—	—	—	—	—	—	—	—	—	1	—	—	—	3	—	—	—	—	—	—	1	1	—	—	6
51— 54	—	—	—	—	—	—	—	—	—	—	—	1	4	3	—	2	—	—	—	1	1	1	1	—	14
55— 58	—	—	—	—	—	—	1	1	1	1	2	—	8	4	3	1	1	3	3	1	1	—	—	—	31
59— 62	—	—	—	—	—	1	3	6	6	5	5	1	8	3	5	1	4	1	2	2	1	3	—	1	58
63— 66	—	—	—	1	4	2	6	6	9	2	17	3	8	5	5	5	3	1	—	2	—	3	2	1	85
67— 70	—	—	2	1	7	7	8	21	17	9	12	6	10	4	1	3	4	1	2	3	6	2	1	1	128
71— 74	—	—	2	5	5	14	6	12	9	14	9	6	7	3	4	1	2	2	1	2	3	—	—	—	107
75— 78	—	1	5	14	6	11	10	18	21	19	16	6	8	3	1	4	—	—	2	2	2	2	—	—	151
79— 82	1	1	2	12	12	18	15	23	20	18	19	5	11	2	—	3	3	1	—	—	2	—	2	—	170
83— 86	1	1	5	6	13	12	8	23	9	16	5	6	4	3	1	2	—	—	3	—	2	—	1	2	123
87— 90	5	2	3	4	18	10	8	17	18	15	6	2	6	—	—	2	—	—	—	—	1	2	1	1	121
91— 94	4	—	3	7	3	11	7	10	7	10	8	2	2	1	—	1	—	2	1	—	—	—	—	—	79
95— 98	2	2	5	4	4	4	5	4	4	3	1	2	—	—	—	—	—	—	1	1	—	—	—	1	43
99—102	6	1	3	—	4	4	1	9	8	8	5	1	—	2	1	1	—	—	—	—	—	—	—	—	54
103—106	6	—	1	5	1	1	2	1	2	1	1	1	—	1	—	—	—	—	—	—	—	—	—	1	24
107—110	4	—	2	2	—	1	2	2	1	4	2	2	—	—	—	—	—	—	—	—	1	—	—	—	23
111—114	3	—	2	5	—	1	—	1	2	1	1	1	—	1	—	—	—	—	—	—	—	—	—	—	18
115—118	1	—	2	—	1	—	—	—	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8
119—122	1	2	2	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	8
123—126	—	1	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	2
Totals	34	11	39	66	78	97	82	155	138	128	110	45	76	38	21	26	17	11	15	14	22	14	8	8	1253

* Pulse rate intervals are 46·95—50·95, 50·95—54·95, etc.

as we are aware, a brief statement in Mackenzie's paper (28) in 1920 to the effect that the systolic pressure increases with pulse rate by about 1 mm. per 5 beats, a conclusion which he reached from records of life insurance data. These records were obtained by many observers under varied conditions, and it is not stated that any correction for age, physique, posture or other factors was applied.

We shall therefore consider this question in some detail, and it will be necessary first to determine the effect of age and physical development on pulse rate in order to correct for these variables.

The distribution of pulse rate with age is shown in Tables 20 and 21, and the relation of mean pulse rate to age is indicated also in Fig. 11.

TABLE 21. *Average Pulse Rate at different Ages (Males).*

Central Ages	No. of cases	Mean pulse rate	Standard deviation	Coefficient of variation
5	34	101·07 ± 1·01	9·55	9·45
6	11	98·40 ± 3·27	16·11	16·37
7	39	92·64 ± 1·57	14·57 ± 1·11	15·73 ± 1·23
8	66	87·25 ± 1·03	12·42 ± ·73	14·23 ± ·85
9	78	83·82 ± ·77	10·12 ± ·55	12·07 ± ·66
10	97	82·97 ± ·69	10·10 ± ·49	12·17 ± ·60
11	82	81·19 ± ·86	11·55 ± ·61	14·23 ± ·76
12	155	81·49 ± ·63	11·54 ± ·44	14·16 ± ·55
13	138	81·88 ± ·76	13·28 ± ·54	16·22 ± ·68
14	128	82·76 ± ·72	12·08 ± ·51	14·60 ± ·63
15	110	78·55 ± ·83	12·88 ± ·59	16·40 ± ·77
16	45	80·68 ± 1·33	13·19 ± ·94	16·34 ± 1·19
17	76	71·58 ± ·84	10·87 ± ·59	15·19 ± ·85
18	38	70·95 ± 1·75	16·03 ± 1·24	22·59 ± 1·84
19	21	67·81 ± 1·50	10·20 ± 1·06	15·04 ± 1·60
20—24	83	71·41 ± ·85	11·45 ± ·60	16·03 ± ·86
25—39	44	72·59 ± 1·43	14·24 ± 1·01	19·62 ± 1·45

PULSE RATE & AGE

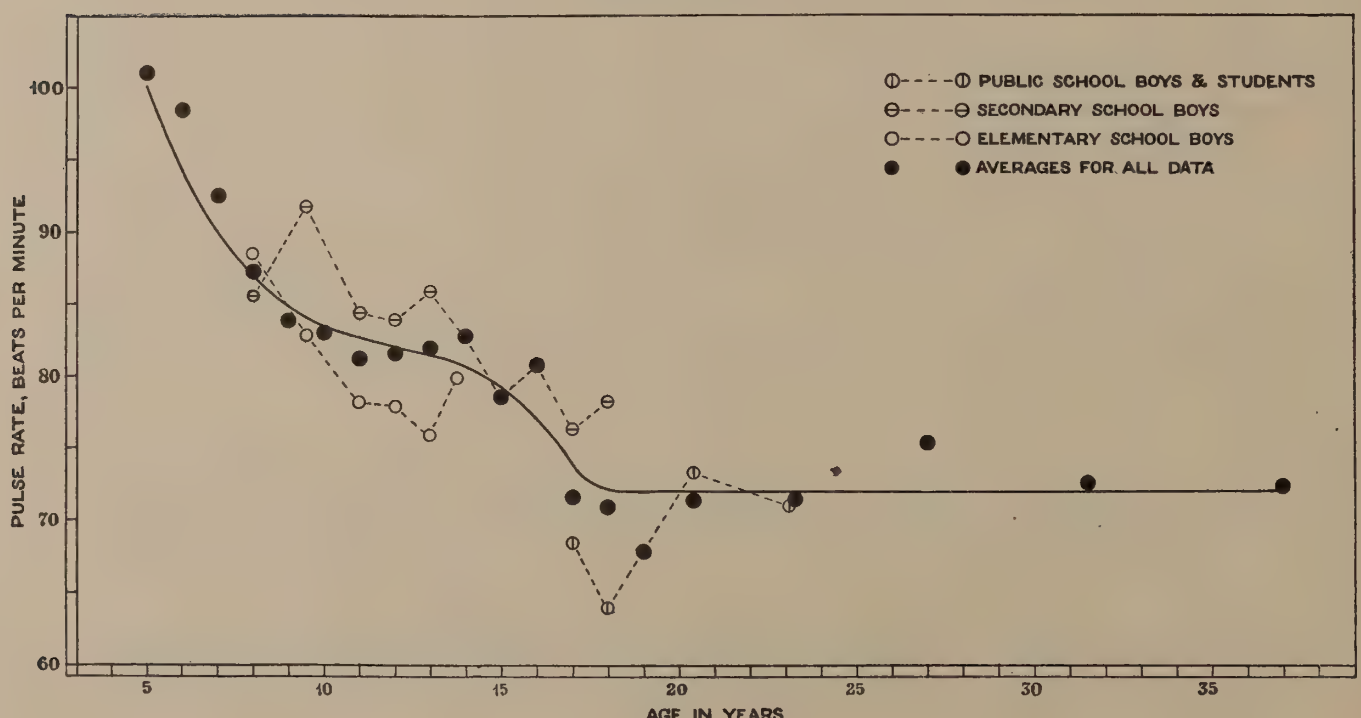


FIG. 11.

The mean pulse rate falls from about 100 per minute at age 5 to about 72 per minute at age 18 at which level it remains apart from accidental variations till middle life. The fall is rapid in the years from 5 to 9, becomes more gradual in the pre-adolescent period and again falls rapidly between 16 and 18 where it reaches the adult level of 71—72 per minute and shows no further change up to 40.

Up to age 17 the pulse rate changes are well represented by a cubic curve, and in Fig. 11 the whole range of age averages has been fitted with two cubics and a straight line continuous with and tangential to each other at ages 17 and 19.

The equations are as follows:

$$A = 5 \text{ to } 17: \; R = 159{\cdot}95 - 18{\cdot}332A + 1{\cdot}4806A^2 - {\cdot}04115A^3,$$
$$A = 17 \text{ to } 19: \; R = 2577{\cdot}41 - 399{\cdot}656A + 21{\cdot}247A^2 - {\cdot}37650A^3,$$
$$A = 19 \text{ to } 39: \; R = 71{\cdot}88,$$

where R = pulse rate per minute, A = age in years.

The variability met with is very high at all ages, the standard deviation being from 10 to 16 beats per minute and coefficient of variation averaging 15·5 °/ₒ. There is no consistent change of variability with age, the pulse rate being as variable in adults as in children.

The correlations between pulse rate and other variables at various ages are given in Table 22. In the case of the correlations with pulse pressure, weight and height, where several years are grouped together, the actual readings have been corrected for age from the age curves before correlating. The correlations between pulse rate and weight, when height is constant, are zero or slightly negative, being apparently significantly negative during adolescence. With stature, when weight is constant, the correlations are slightly positive during adolescence and adult life, being of the order of ·15. During childhood there appears to be no correlation between pulse rate and physical development.

The correlation coefficients between pulse rate and *systolic pressure* are uniformly positive and show a tendency to decrease slightly with age from childhood to adolescence and to increase considerably from age 20 onwards, becoming as high as ·64 for age group 26—39 (mean age 30). Other variations are accounted for by the smallness of the age groups. The correction for weight and height makes little difference to these values. The calculated regressions of systolic pressure on pulse rate are plotted in Fig. 12, and have been smoothed by fitting the parabola

$$b = {\cdot}372 - {\cdot}0374A + {\cdot}00135A^2 \text{ up to age 25.}$$

The smoothed values are given in Table 22, and decrease from ·194 (mm. of pressure per unit rise in pulse rate per minute) at age 7 to ·148 at 13, then increasing to ·346 at age 25; at average age 30 the actual value is ·477.

This means that during later childhood and adolescence an excess or defect of systolic pressure of 1 mm. accompanies an excess or defect of pulse rate of about 6 per minute, whilst in early adult life 1 mm. rise or fall in pressure accompanies a change of about 3 per minute, or even 2 per minute, between 25 and 40. The effect of these corrections is shown in Fig. 17, in which two series of correction curves have

been drawn, (1) curves of systolic pressure with age for constant deviations of pulse rate from the age average (i.e. from smoothed curve of Fig. 11); (2) curves of systolic pressure with age for constant pulse rate. The latter (dotted) curves will be found most useful for clinical purposes, since for a given age and pulse rate the average pressure can be read off at once without further calculation or reference to other tables. The curves have been drawn for intervals of 10 beats per minute, but it is easy to interpolate between them for intermediate pulse rates. We have not continued the curves beyond 25, as the data on which our calculations are based above this age are not

TABLE 22. *Correlation between Pulse Rate and other Variables.*

Age centre	Systolic pressure: Correlation with pulse rate	Systolic pressure: Regression on pulse rate*: Actual	Systolic pressure: Regression on pulse rate*: Smoothed†	Diastolic pressure: Correlation with pulse rate	Diastolic pressure: Regression on pulse rate*: Actual	Diastolic pressure: Regression on pulse rate*: Smoothed‡	Pulse pressure: Correlation with pulse rate corrected for age from curves	Weight: Correlation with pulse rate corrected for age and height	Height: Correlation with pulse rate corrected for age and weight
7	·187 ± ·066	·142	·194	·343 ± ·055	·186	·231			
8			·180			·192			
9	·182 ± ·050	·166	·169	·158 ± ·068	·130	·158			
10			·159			·127	·054 ± ·029	– ·037 ± ·028	– ·031 ± ·028
11	·131 ± ·075	·130	·153	·148 ± ·062	·096	·100			
12	·234 ± ·053	·256	·149	·227 ± ·056	·144	·078			
13	·106 ± ·057	·100	·148	·113 ± ·058	·057	·061			
14	·148 ± ·048	·151	·149	·093 ± ·050	·067	·046			
15	·190 ± ·060	·180	·154	·031 ± ·065	·026	·037	·117 ± ·034	– ·160 ± ·035	·140 ± ·035
16	·151 ± ·060	·152	·161	– ·108 ± ·062	– ·076	·032			
17			·170			·031			
18	·181 ± ·089	·143	·183	– ·007 ± ·088	– ·005	·034	·175 ± ·087	– ·100 ± ·090	·044 ± ·090
19			·199			·042			
20			·217			·053			
21			·237			·070			
22			·260			·090			
23			·286			·115	·172 ± ·041	– ·091 ± ·058	·148 ± ·057
24			·316			·146			
25	·350 ± ·051	·361	·346	·250 ± ·055	·188	·177			
30 (26—39)	·639 ± ·045	·477	—			—			

* Mm. rise in pressure per 1 beat per minute increase in pulse rate.
† By fitting parabola $y = ·372 - ·0347x + ·00135x^2$ up to age 25.
‡ By fitting parabola $y = ·626 - ·0711x + ·00213x^2$ up to age 25.

very large; the values for 25 may be used for ages up to 40 without, we believe, very serious error.

This diagram is of considerable practical importance in that it enables us to approximately correct for the effect of psychological factors such as nervousness which may introduce considerable errors in blood-pressure measurements. Thus we may occasionally meet with a pulse rate as high as 110 due to this cause, the systolic pressure being concurrently elevated in consequence by as much as 15 mm. in adults, and as it is not always practicable to wait until the patient's nervousness has entirely subsided, it is of great value to be able to rapidly estimate the necessary correction.

Table 30 has been drawn up with the object of enabling the practitioner to quickly find the average systolic pressure to be expected in an individual of given age, pulse rate and weight, and will be referred to again in the next section.

The correlations with *diastolic pressure* decrease from ·34 at ages 7—8 to zero at 15, and become insignificantly negative from 16 to 19, increasing in early adult life again to ·25 for age group 20—39. The zero correlation during late adolescence may be due to the rapid increase of diastolic pressure and decrease in pulse rate which

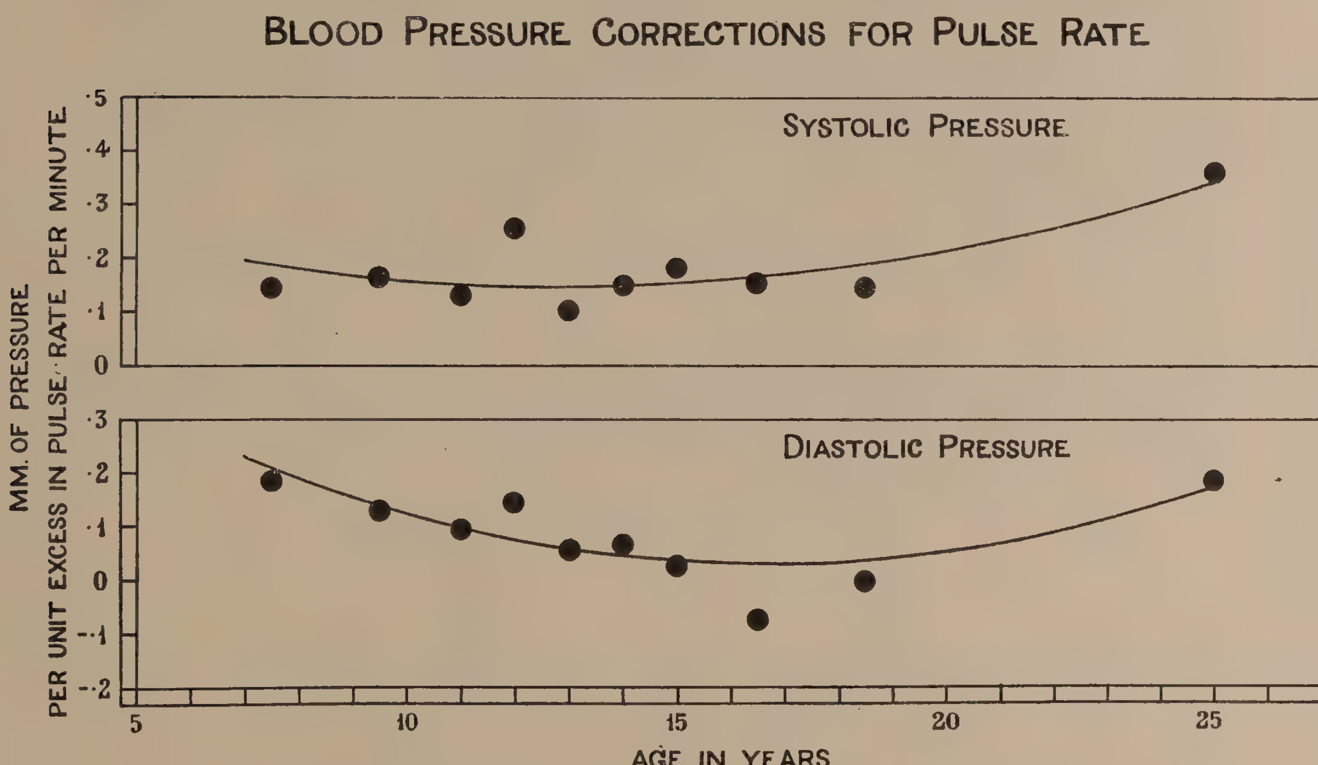


FIG. 12.

occur at this period. The regression coefficients are plotted in Fig. 12 and have been smoothed by fitting the parabola

$$b = ·626 - ·0711A + ·00213A^2 \text{ up to age 25.}$$

The smoothed values (Table 22) decrease from ·23 at age 7 to ·03 at 17, increasing again to ·18 at 25. This means that in childhood, and between 25 and 40, an excess or defect of pressure of 1 mm. accompanies a pulse rate excess or defect of about 5 per minute, whilst in adolescence the correction falls as low as 1 mm. for 30 beats. In Fig. 19 correction curves have been drawn in the same way as for the systolic pressure, enabling the average diastolic pressure for given age and pulse rate to be immediately found.

Table 31 combines the corrections for age, height, and pulse rate, and will be referred to again. The correlation between pulse rate and pulse pressure is insignificant in childhood, but becomes slightly positive in adolescence and adult life (·17).

Pulse Pressure × Pulse Rate product.

The somewhat confused statements sometimes made that pulse pressure and pulse rate tend to vary reciprocally are based on the observation that whilst pulse rate falls throughout life, the pulse pressure tends to rise, so that the mean values of the product in childhood and adult life are approximately the same. Amongst individuals of the same age, however, there is a slight positive correlation between these two variables, so that the statement cannot be applied generally. On the contrary, influences which tend to raise the pulse rate in a given individual often tend also to raise the pulse pressure. In change of posture of the body, however, as we have shown, the reciprocal relation between average pulse rate and average pulse pressure seems to hold good.

Erlanger and Hooker(35) were the first to suggest that this product provided an index of work done by the heart in maintaining the circulation, and MacWilliam and Melvin (21), Sewall(33) and others have also advocated its measurement.

Faber and James(54) found that the mean product at ages from 4 to 16 showed only a slight rise (from 2880 to 3100) and was also approximately the same in the two sexes.

The only other published data from which this product can be worked out are the figures given by Smythe(52) for 100 males aged 18 to 40. From these we have calculated the mean value of the product for various ages, and have tabulated them below as they are of interest for comparison with our own figures.

Ages	No. of cases	Mean value of product
18—19	10	3936
20—25	19	3000
26—30	34	2935
31—35	23	3065
36—40	14	2820

In Table 23 we have given the distribution of the values of the product with age from our own results; the means and S.D.'s are given in Table 24, and the relation with age is also shown graphically in Fig. 13. It appears from these results that the mean value of the product remains in the neighbourhood of 3200 up to age 10 and then increases slowly to 13 and more rapidly during adolescence to a maximum of over 4000 at age 16, after which age it again falls almost to the original level of 3200 at about 20. After 25 it again shows a tendency to rise somewhat, the average value for ages 25—39 being 3465.

That is to say, the value of the product during the period of uniform growth to age 12 is fairly constant, and the same as during early adult life, while during the period of adolescence and most rapid growth it reaches a level much above the adult value. This fact is of considerable interest if we agree to the contention that the product can be taken as an index of cardiac energy expended per minute in maintaining the circulation. It is clear that, if V = volume of blood expelled from heart into aorta at each systole, R = no. of systolic contractions per minute (i.e. pulse

TABLE 23. *Distribution of "Cardiac Output" Product with Age (Males).*

AGE

Pulse Pressure × Rate Product*	Centred at 7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25—29	30—34	35—39	Over 40 (Mean 49)	Totals
1250—1749	—	—	1	—	—	1	1	3	—	2	—	—	—	—	—	—	—	—	—	—	—	—	8
1750—	2	4	8	9	6	12	17	6	3	1	6	1	4	3	2	2	1	2	2	4	1	—	96
2250—	8	15	17	16	11	22	18	20	15	2	13	7	4	4	6	4	1	1	4	—	1	2	191
2750—	6	14	15	19	23	26	30	21	21	3	12	12	5	4	3	—	5	2	4	5	1	4	235
3250—	5	12	10	15	11	23	17	20	17	9	10	4	3	5	2	1	4	8	5	—	1	1	183
3750—	4	5	7	7	6	15	24	17	12	7	9	4	3	4	1	3	1	1	2	2	1	—	135
4250—	1	2	3	5	4	10	12	16	11	7	12	1	1	4	2	1	1	—	4	1	1	—	99
4750—	—	5	2	1	3	8	2	11	10	1	4	5	—	1	—	—	—	—	—	1	2	—	56
5250—	—	1	1	2	3	2	2	6	7	6	5	1	—	—	—	—	2	—	—	—	—	—	38
5750—	—	1	—	—	—	3	1	1	5	3	3	1	—	—	1	—	—	—	—	1	—	—	20
6250—	—	—	—	1	—	3	—	3	3	2	1	1	—	—	—	—	—	—	—	—	—	—	14
6750—	—	—	—	—	—	—	1	—	2	—	—	—	—	—	—	—	—	—	1	—	—	—	4
7250—	—	—	—	—	—	—	—	—	1	1	—	1	1	—	—	—	—	—	—	—	—	—	4
7750—	—	—	—	—	—	—	—	—	—	1	1	—	—	—	—	—	—	—	—	—	—	—	2
8250—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
8750—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1
10,250—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	1
Totals	26	59	64	75	67	125	127	124	107	45	76	38	21	25	17	11	15	14	22	14	8	8	1088

* The product being calculated to the nearest unit, the intervals are 1249·5—1749·5, etc.

TABLE 24. *Average Pulse Pressure × Pulse Rate Product at different Ages (Males).*

Age centre	No. of cases	Mean value of product	Standard deviation	Coefficient of variation
7	26	3076 ± 85	645 ± 60	21·0 ± 2·0
8	59	3305 ± 80	909 ± 56	27·5 ± 1·8
9	64	3078 ± 69	822 ± 49	26·7 ± 1·7
10	75	3206 ± 69	887 ± 49	27·7 ± 1·6
11	67	3291 ± 71	865 ± 50	26·3 ± 1·6
12	125	3460 ± 64	1067 ± 46	30·8 ± 1·4
13	127	3397 ± 69	1150 ± 49	33·9 ± 1·6
14	124	3653 ± 66	1091 ± 47	29·9 ± 1·4
15	107	3953 ± 81	1246 ± 57	31·5 ± 1·6
16	45	4322 ± 142	1411 ± 100	32·6 ± 2·6
17	76	3756 ± 95	1231 ± 67	32·8 ± 2·0
18	38	3697 ± 136	1241 ± 96	33·6 ± 2·9
19	21	3214 ± 175	1192 ± 124	37·1 ± 4·4
20—21	42	3297 ± 97	928 ± 68	28·1 ± 2·2
22—24	40	3287 ± 89	831 ± 63	25·3 ± 2·0
25—29	22	3477 } 3465 ± 113	1116 ± 80	32·2 ± 2·5
30—34	14	3321 }		
35—39	8	3687 }		

rate), V = velocity of blood, P = head of pressure developed in the aorta during each systole, s = specific gravity of blood, we have the relation

$$\text{Total energy expended by heart per minute} = K_1 . V . P . R + K_2 . s . V . v^2,$$

where the K's are constants. The second term is very small compared to the first and for our purposes may be neglected. The value of V cannot be measured readily, and it is no doubt variable within certain limits in individuals of the same age, weight and height, but we may perhaps make two assumptions:

(1) Since clinical observations of the size of the heart at various ages suggest that the heart grows in size in proportion to the rest of the body during childhood and adolescence, and since there is no evidence to show that its average efficiency in emptying itself alters with growth to any extent, we may assume that during the period of growth the mean values of V for large groups of growing individuals are directly

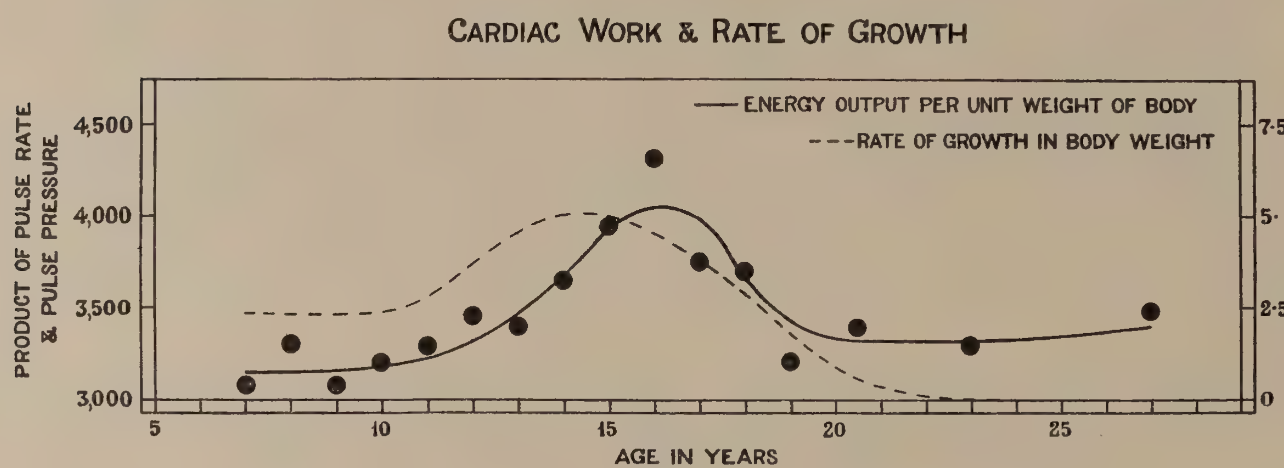


FIG. 13.

proportional to the mean body weights of these groups*. (2) We may assume that the average value of V remains fairly constant in adults up to middle life.

If the last assumption be correct then:

$$\text{Mean expenditure of cardiac energy per minute for a group of young adults} = K_3 . \overline{P \times R}$$

(where $\overline{P \times R}$ is the mean value of product $P \times R$ for that group), and we arrive at the conclusion that, in comparing large groups of young adults aged 20 and upwards, of the same sex, the *mean* product of pulse rate and pulse pressure is directly proportional to the *mean* work done by the heart per minute.

* Some observations by Benneke (72) suggest that this may not be true during adolescence; his figures yield the same ratio of heart volume to body weight during childhood as in adults, but a lower ratio for ages 13—14. If this be so, the accentuation of the pulse pressure might be compensatory to a lagging behind in growth of the heart volume. The data are insufficient to reach any conclusion on the matter.

If our first assumption be correct we arrive at the relation

$$\left.\begin{array}{c}\text{Mean expenditure of cardiac energy per minute for a}\\ \text{group of individuals of a given age}\end{array}\right\} = K_4 . \overline{W} . \overline{P \times R},$$

where $\overline{W}$ = mean weight at that age,

and $\overline{P \times R}$ = mean value of pulse pressure × pulse rate product for that age.

We have tabulated the values of $\overline{W} \times \overline{P \times R}$ for various ages below (obtained from the smoothed values of $\overline{W}$ and $\overline{P \times R}$).

Age centre	$\overline{W}$	$\overline{P \times R}$	$\overline{W} \times \overline{P \times R}$	Age	$\overline{W}$	$\overline{P \times R}$	$\overline{W} \times \overline{P \times R}$
7	20·85	3150	70,677	15	47·67	3920	186,866
8	23·14	3150	72,891	16	52·44	4050	212,382
9	25·43	3160	80,359	17	56·59	3880	219,569
10	27·72	3180	88,150	18	59·90	3630	217,437
11	30·01	3220	96,632	19	62·24	3430	213,483
12	33·09	3320	109,859	20	63·61	3300	209,913
13	37·54	3470	130,264	21	64·03	3240	207,457
14	42·57	3650	155,380				

It appears from this that the mean value of the product $\overline{W} \times \overline{P \times R}$ increases with age up to a maximum at age 17 and then slightly falls. If our assumptions be justified we must conclude that when the age of 16 has been reached, the average heart is performing as much or more gross work per minute than in adult life, in spite of the fact that it has presumably not attained its full size.

We may attack the problem in another way without involving any assumption other than the reasonable one that at different ages the mean value of V (volume of systole) is directly proportional to the mean weight of the heart at that age, in which case we have the relation

$$\left.\begin{array}{c}\text{Mean expenditure of cardiac energy per unit weight}\\ \text{of heart per minute at any age}\end{array}\right\} = K_5 . \overline{P \times R}.$$

From Table 24 and Fig. 13, this leads at once to the conclusion that the mean output of energy per gramme of heart muscle is the same during childhood as during young adult life, but is markedly increased during the period when rate of growth is greatest (15—17), reaching then a maximum value about 27 °/ₒ higher than the value for young adults. This seems to indicate that the strain on the heart muscle is greater at this period than at any other, and though modern authorities tell us that the heart in youth never breaks down by mechanical strain alone, such increased strain must undoubtedly mean an increased susceptibility of the myocardium and valves to rheumatic infection about the adolescent period. It may also explain why physical signs suggestive of valvular lesions (especially auscultatory signs) are so often met with in adolescents, without having any real pathological significance.

It is our opinion that the routine examination of blood pressure during medical inspection of Secondary School boys, and the careful observation of any boys found to

have unduly high pressures might be of considerable value not only for the solution of these problems but in the actual prevention of cardiac disease originating in adolescence.

A comparison of the curve of pulse pressure × pulse rate product with age, with the age curve of rate of growth in body weight (Fig. 13), is interesting, as they show some similarity, and we have therefore plotted them on the same diagram. The latter curve is derived from the weight curve by differentiating with respect to age; thus we obtain

for ages 5 to 11: $dW/dA = 2{\cdot}29$; for ages 21 to 39: $dW/dA = 0$;

and for ages 11 to 21: $dW/dA = -97{\cdot}42 + 19{\cdot}039A - 1{\cdot}1910A^2 + {\cdot}02780A^3 - {\cdot}000178A^4$.

The similarity between the curves suggests that there may be a direct relation between rate of output of cardiac energy and rate of body growth at the time, and it seems a reasonable supposition that a more powerful circulation is needed to meet the needs of the body during rapid growth than after growth has ceased. This may partly serve to explain the excessive output during adolescence, and also one's impression that symptoms of "cardiac overstrain" or dilatation during adolescence seem to occur most frequently in youths who are growing with abnormal rapidity.

(6) Physical Development.

The influence of physical development on blood pressure has not been worked out in detail as far as we know. Wolfensen-Kriss (59) makes the general statement that the blood pressure in children varied with height and weight rather than with age. Oliver (40) makes the following statement in his book (p. 114): "Small, light subjects, especially women, have generally low arterial pressures, so that in such cases a rise above the normal for age...should be regarded as more significant than in subjects of average build and weight. Broad or largely built subjects, especially when obese, often yield higher arterial pressures, which for them are generally not abnormal."

Faught (30), speaking of children, says that the physical development factor is more important than in adults, and that the tallness of a child often has a greater bearing on blood pressure than has body weight. Speaking of adults he says "the physical fitness and muscular development of the individual affects slightly the average normal blood pressure readings."

Mackenzie (28), from Life Insurance statistics, concluded that persons from 20 to 29 °/₀ over average weight had a mean systolic pressure about 3 mm. above the general average, whilst 30 to 39 °/₀ overweights had an average excess of 4 mm., age and height being neglected; whilst the mean systolic pressure for persons under 67 inches in height was 1 mm. less than for persons over 67 inches.

Faber and James (54) in their analysis of measurements on American school children dismiss the matter in a footnote by saying that they find the range of distribution of blood pressure with height and weight to be as great as with age.

In the hope of reaching a more definite conclusion on this question, we have recorded the weight and height of all the subjects we have examined wherever possible. The weights and heights were taken without shoes, and recorded in metric measure. The distributions of weight and height with age are shown in Tables 25, 26;

TABLE 25. *Distribution of Weight with Age (Males).*

Weight*	Age: Centred at																				25—29	30—34	35—39	Totals
Kgms.	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
12—15	8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	8
16—19	25	1	10	8	3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	47
20—23	3	4	21	32	22	7	5	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	98
24—27	—	1	2	23	30	35	17	10	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	120
28—31	—	—	—	5	9	25	28	46	27	3	3	1	—	—	—	—	—	—	—	—	—	—	—	147
32—35	—	—	—	1	—	3	16	45	39	21	4	—	1	—	—	—	—	—	—	—	—	—	—	130
36—39	—	—	—	—	—	1	4	22	27	31	7	3	—	—	—	—	—	—	—	—	—	—	—	95
40—43	—	—	—	—	—	—	2	9	25	17	18	2	—	—	—	—	—	—	—	—	—	—	—	73
44—47	—	—	—	—	—	—	—	3	12	26	24	3	4	1	—	—	—	—	—	—	—	—	—	73
48—51	—	—	—	—	—	—	1	2	3	20	18	5	10	4	1	1	—	—	—	—	—	—	—	65
52—55	—	—	—	—	—	—	—	—	1	7	14	16	16	4	2	3	1	—	—	2	3	1	1	71
56—59	—	—	—	—	—	—	—	—	—	3	13	3	15	10	4	2	6	2	3	5	6	1	4	77
60—63	—	—	—	—	—	—	—	—	—	—	5	6	12	9	6	10	3	3	3	3	4	3	1	68
64—67	—	—	—	—	—	—	—	—	—	—	4	5	11	6	5	4	3	5	2	2	7	3	1	58
68—71	—	—	—	—	—	—	—	—	—	—	—	1	2	3	1	2	2	—	4	2	2	3	1	23
72—75	—	—	—	—	—	—	—	—	—	—	—	—	4	1	2	4	2	—	—	—	2	3	—	18
76—79	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	2	—	—	1	—	4
80—83	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
84—87	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1
88—91	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1
TOTALS	36	6	33	69	64	71	73	141	135	129	110	45	76	38	21	26	17	11	15	14	24	15	8	1177

* Readings being taken to the nearest hectogramme, the intervals are 11·95—15·95, 15·95—19·95, etc.

TABLE 26. *Distribution of Height with Age (Males).*

Height*	Age: Centred at																				25—29	30—34	35—39	Totals
cm.	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24				
91— 96	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
97—102	15	1	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	17
103—108	14	3	6	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	24
109—114	5	2	13	6	3	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	31
115—120	—	—	11	22	18	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	55
121—126	—	—	3	27	23	23	5	4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	85
127—132	—	—	—	13	10	27	19	21	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	94
133—138	—	—	—	—	10	12	16	37	15	2	—	1	—	—	—	—	—	—	—	—	—	—	—	93
139—144	—	—	—	—	—	3	23	45	47	13	4	—	1	—	—	—	—	—	—	—	—	—	—	136
145—150	—	—	—	—	—	—	6	20	31	36	5	1	—	—	—	—	—	—	—	—	—	—	—	99
151—156	—	—	—	—	—	—	2	9	23	23	22	2	—	—	—	—	—	—	—	—	—	—	—	81
157—162	—	—	—	—	—	—	1	5	6	31	37	7	8	2	1	1	1	—	—	1	1	—	1	103
163—168	—	—	—	—	—	—	—	—	5	14	24	13	20	5	5	6	4	—	1	3	7	3	4	114
169—174	—	—	—	—	—	—	—	—	1	7	9	10	20	14	5	9	5	6	5	4	7	6	2	110
175—180	—	—	—	—	—	—	—	—	—	2	8	9	19	13	6	5	5	3	6	4	8	6	1	95
181—186	—	—	—	—	—	—	—	—	—	—	1	2	5	4	4	5	1	2	3	2	1	—	—	30
187—192	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	3
TOTALS	36	6	33	69	64	71	73	141	131	129	110	45	76	38	21	26	16	11	15	14	24	15	8	1172

* Readings being taken to the nearest millimetre, the intervals are 90·95—96·95, 96·95—102·95, etc.

the means and standard deviations for each age in Table 27, and the age curves in Figs. 14, 15.

The mean weights up to age 11 lie approximately on a straight line; the gradient changes during adolescence, and from 21 onwards the weight remains approximately constant. We have therefore fitted to the whole series a straight line up to age 11, a horizontal straight line from 21 to 40, and a quintic curve continuous with and

TABLE 27. *Average Weights and Heights at different Ages* (*Males*).

Central ages	No. of cases	Mean weight	Standard deviation	Mean height	Standard deviation
5	36	17·54 ± ·24	2·14 ± ·17	103·87 ± ·53	4·74 ± ·38
6	6	18·95 ± ·71	2·31 ± ·45	107·95 ± 1·02	4·12 ± ·80
7	33	20·98 ± ·22	1·88 ± ·16	113·95 ± ·58	4·96 ± ·41
8	69	23·57 ± ·26	3·15 ± ·18	121·86 ± ·43	5·30 ± ·30
9	64	24·76 ± ·24	2·83 ± ·17	124·51 ± ·54	6·46 ± ·39
10	71	27·47 ± ·12	1·48 ± ·08	128·09 ± ·56	6·95 ± ·39
11	73	30·39 ± ·38	4·80 ± ·27	137·02 ± ·61	7·71 ± ·43
12	141	33·35 ± ·29	5·04 ± ·20	140·33 ± ·44	7·76 ± ·31
13	135*	36·94 ± ·32	5·47 ± ·22	146·48 ± ·46	7·84 ± ·33
14	129	42·35 ± ·40	6·71 ± ·28	154·67 ± ·55	9·31 ± ·39
15	110	48·46 ± ·51	7·99 ± ·36	161·37 ± ·53	8·30 ± ·38
16	45	53·86 ± ·86	8·50 ± ·60	167·95 ± ·92	9·13 ± ·65
17	76	58·32 ± ·60	7·73 ± ·43	171·71 ± ·62	8·04 ± ·44
18	38	59·95 ± ·68	6·24 ± ·48	173·84 ± ·63	5·76 ± ·45
19	21	62·33 ± ·87	5·92 ± ·62	173·95 ± 1·00	6·79 ± ·71
20	26	63·33 ± ·84	6·36 ± ·59	173·57 ± ·87	6·55 ± ·61
21	17†	63·13 } 64·27 ± ·64	7·17 ± ·45	172·33 } 174·31 ± ·52	5·82 ± ·37
22—24	40	64·75		175·10	
25—29	24	62·78 } 63·74 ± ·71	7·22 ± ·50	172·20 } 171·82 ± ·52	5·33 ± ·37
30—34	15	66·22		173·15	
35—39	8	60·45		168·20	

* 131 cases for height. † 16 cases for height.

tangential to both at ages 11 and 21. This curve is shown in Fig. 14, and is represented by the equations:

for ages 5 to 11: $W = 4{\cdot}825 + 2{\cdot}290A$,

for ages 11 to 21: $W = 382{\cdot}20 - 97{\cdot}424A + 9{\cdot}5196A^2 - {\cdot}39701A^3 + {\cdot}006950A^4 - {\cdot}0000356A^5$,

for ages 21 to 39: $W = 64{\cdot}03$,

where W = weight in grammes, A = age in years.

It may be noted that, if produced downwards, the first curve would give a value of 7·115 kgms. as average weight at one year of age, a value about 1 kgm. below that found for babies of that age in a recent investigation of Baby Clinic data of a northern manufacturing town (70).

The mean heights (see Fig. 15) lie approximately on a straight line up to age 13, where the gradient is slightly increased, and the adult level is reached about age 18. We have fitted to these points a straight line up to 13, a horizontal line from 18 onwards, and a cubic curve continuous with and tangential to both at 13 and 18.

WEIGHT AND AGE

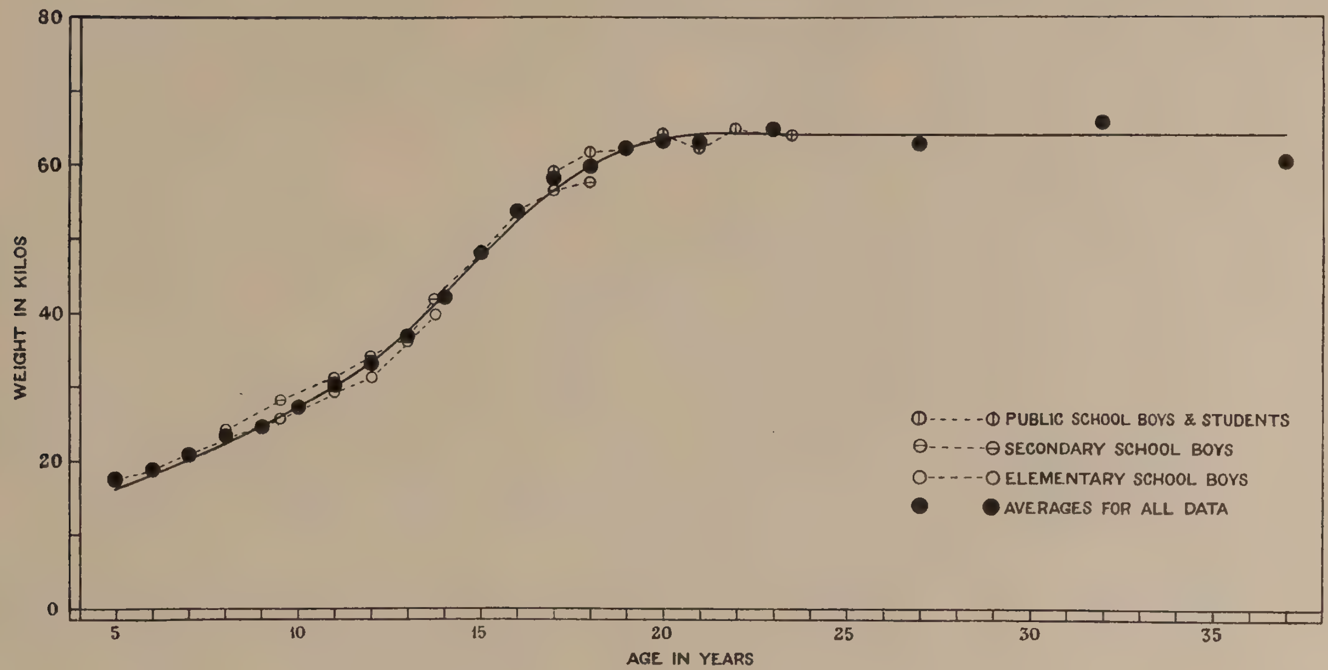


FIG. 14.

HEIGHT & AGE

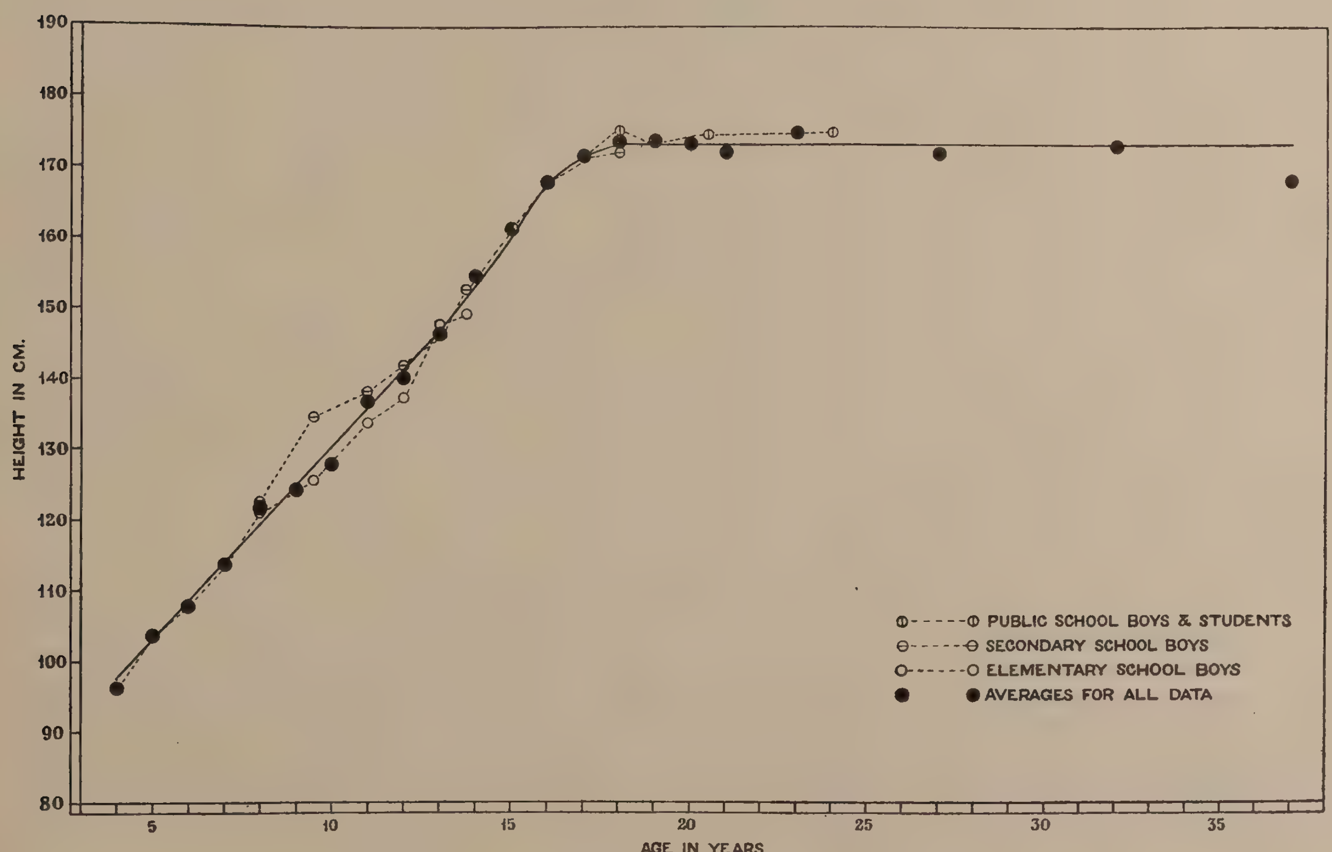


FIG. 15.

The equations of the continuous curve are:

for ages 5 to 13: $H = 75{\cdot}61 + 5{\cdot}490A$,

for ages 13 to 18: $H = 689{\cdot}19 - 123{\cdot}368A + 8{\cdot}9322A^2 - {\cdot}20390A^3$,

for ages 18 to 39: $H = 173{\cdot}45$,

where H = height in cm., A = age in years.

In Table 28 the correlations and regressions of weight with other variables are tabulated. The regression of weight on height (kgms. per cm.) increases from about ·3 at age 7 to about ·75 in adolescents and young adults. The regression coefficients have been plotted in Fig. 16 and smoothed by a spline curve.

The regressions of height on weight (see Table 29) decrease from about 1·8 cm. per kgm. at 7 to about ·6 in adults. These have also been smoothed in Fig. 16.

The correlations between *systolic pressure* and weight (Table 28) are of the order ·3 during growth, but fall to ·1 when adult age is reached. When height is constant these are somewhat reduced during adolescence, but slightly increased for adults; for early ages 7 to 9 the corrected correlation is zero or slightly negative, from which it would appear that at this period height is of more importance than weight, a fact difficult of explanation. The correlations of systolic pressure and height (Table 29) are also of the order ·3 during growth, falling to zero at adult age. When weight is constant, the correlation with height becomes zero or slightly negative, except at ages 7 to 9 for which it remains positive; the mean corrected coefficient for all ages is + ·019, and we are therefore justified in assuming that, with the possible exception of the earliest ages, the apparent relationship between systolic pressure and height is entirely due to the correlations of both variables with weight. In applying corrections to the systolic pressure for physical development, it will therefore be sufficient to correct for weight alone. The actual regressions on height, however, have been plotted in Fig. 16 and smoothed with a spline curve—they fall continuously from ·63 mm. of pressure per cm. of height at age 7 to zero in adult age.

The regressions of systolic pressure on weight are also shown in Fig. 16, and the smoothed values fall from ·85 mm. per kgm. at age 7 to a minimum of ·20 at 20. This means that amongst a group of boys between ages $14\frac{1}{2}$ and $15\frac{1}{2}$, for example, those who were 2 kgms. overweight would tend to have a pressure of 1 mm. above the average, whilst in a group of young adults those who were 5 kgms. overweight would tend to have a pressure of 1 mm. above the average.

On the basis of these smoothed regressions we have constructed the series of correction curves in Fig. 18 at intervals of 5 kgms. There are two interesting series of lines, (1) plain lines showing the systolic pressure at different ages to be expected in individuals who are 5, 10, 15, ... kgms. over or under average weight for their age, (2) dotted lines showing systolic pressure to be expected in individuals of constant weight at various ages. The latter series of lines will be the most useful for clinical purposes, since the expected systolic pressure for an individual of known age and weight can be at once read off without any calculation whatever. For the benefit of those who prefer a table

TABLE 28. *Correlation between Weight and Blood Pressure Variables.*

Age: Centred at	Regression of weight on height: Actual	Regression of weight on height: Smoothed	Systolic pressure: Correlation with weight	Systolic pressure: Regressions* Actual	Systolic pressure: Regressions* Smoothed	Systolic pressure: r Height constant	Diastolic pressure: Correlation with weight	Diastolic pressure: Regressions* Actual	Diastolic pressure: Regressions* Smoothed	Diastolic pressure: r Height constant	Pulse pressure: Correlation with weight corrected from age curves	Pulse pressure: Do. corrected for height and pulse rate	Pulse rate pressure product: Correlation with weight corrected from age curves	Pulse rate pressure product: Do. corrected for height
7	·346	·305	·230 ± ·051	·817	·855	−·027	·107 ± ·062	·293	·425	−·120	·192 ± ·028	·135	·138 ± ·030	·119
8		·370			·845				·410					
9	·407	·430			·825	−·089	·181 ± ·110	·329	·390	−·281				
10		·485	·271 ± ·078	·838	·795	·059	·086 ± ·089		·365	−·090				
11	·473	·535	·280 ± ·075	·662	·755	·280	·070 ± ·087		·337	−·074				
12	·529	·580	·341 ± ·058	·820	·705	·297	·231 ± ·067	·374	·307	·055				
13	·584	·620	·286 ± ·053	·670	·645	·266	·127 ± ·058	·202	·277	·071				
14	·631	·655	·406 ± ·045	·739	·575	·238	·232 ± ·052	·299	·249	·108	·194 ± ·033	·165	·165 ± ·033	·154
15	·769	·685	·304 ± ·058	·456	·495	·121	·146 ± ·063	·172	·224	−·060				
16	·754	·710	·194 ± ·059	·307	·415	·120	·090 ± ·059	·095	·201	−·013				
17		·730			·345				·184					
18	·650	·748	·096 ± ·090	·168	·285	·084	·288 ± ·083	·456	·172	·250				
19		·765			·240				·164					
20	·754	·780	·118 ± ·057	·211	·205	·143	·127 ± ·057	·159	·160	·045	−·012 ± ·058	·092	·023 ± ·057	·069
25 (21—39)		·754			·211				·159					

* Millimetres of pressure per kilogramme of weight.

TABLE 29. *Correlation between Height and Blood Pressure Variables.*

Age: Centred at	Regression of height on weight: Actual	Regression of height on weight: Smoothed	Systolic pressure: Correlation with height	Systolic pressure: Regressions* Actual	Systolic pressure: Regressions* Smoothed	Systolic pressure: r Weight constant	Diastolic pressure: Correlation with height	Diastolic pressure: Regressions* Actual	Diastolic pressure: Regressions* Smoothed	Diastolic pressure: r Weight constant	Pulse pressure: Correlation with height corrected from age curves	Pulse pressure: Do. corrected for weight and pulse rate	Pulse rate pressure product: Correlation with height corrected from age curves	Pulse rate pressure product: Do. corrected for weight
7	1·710	1·93	·302 ± ·062	·555	·630	·223	·247 ± ·066	·303	·335	·254	·129 ± ·033	−·047	·073 ± ·030	−·064
8		1·83			·603				·320					
9	1·654	1·72	·386 ± ·075	·664	·569	·298	·300 ± ·058	·389	·305	·455				
10		1·60	·283 ± ·076	·386	·530	·105			·290	·158				
11	1·630	1·47	·169 ± ·079	·257	·487	−·167	·120 ± ·085	·253	·276	·124				
12	1·363	1·33	·221 ± ·062	·353	·440	−·139	·239 ± ·067	·268	·263	·084				
13	1·217	1·20	·172 ± ·056	·273	·390	−·134	·106 ± ·058	·115	·250	−·002				
14	1·060	1·08	·339 ± ·047	·450	·340	·013	·209 ± ·052	·203	·238	·034	·136 ± ·034	−·051	·107 ± ·034	−·047
15	·838	·97	·293 ± ·058	·431	·292	·086	·226 ± ·061	·286	·228	·185				
16	·811	·86	·156 ± ·060	·239	·246	·023	·137 ± ·060	·144	·220	·091				
17		·77			·202				·213					
18	·622	·70	·049 ± ·090	·079	·160	−·016	·152 ± ·077	·223	·206	−·042				
19		·64			·120				·201					
20	·593	·60	·018 ± ·058	·036	·085	−·083	·141 ± ·057	·197	·197	·076	−·100 ± ·057	−·173	−·035 ± ·057	−·067
25 (21—39)		·59			·036				·197					

* Millimetres of pressure per cm. of height.

BLOOD PRESSURE CORRECTIONS FOR WEIGHT & HEIGHT

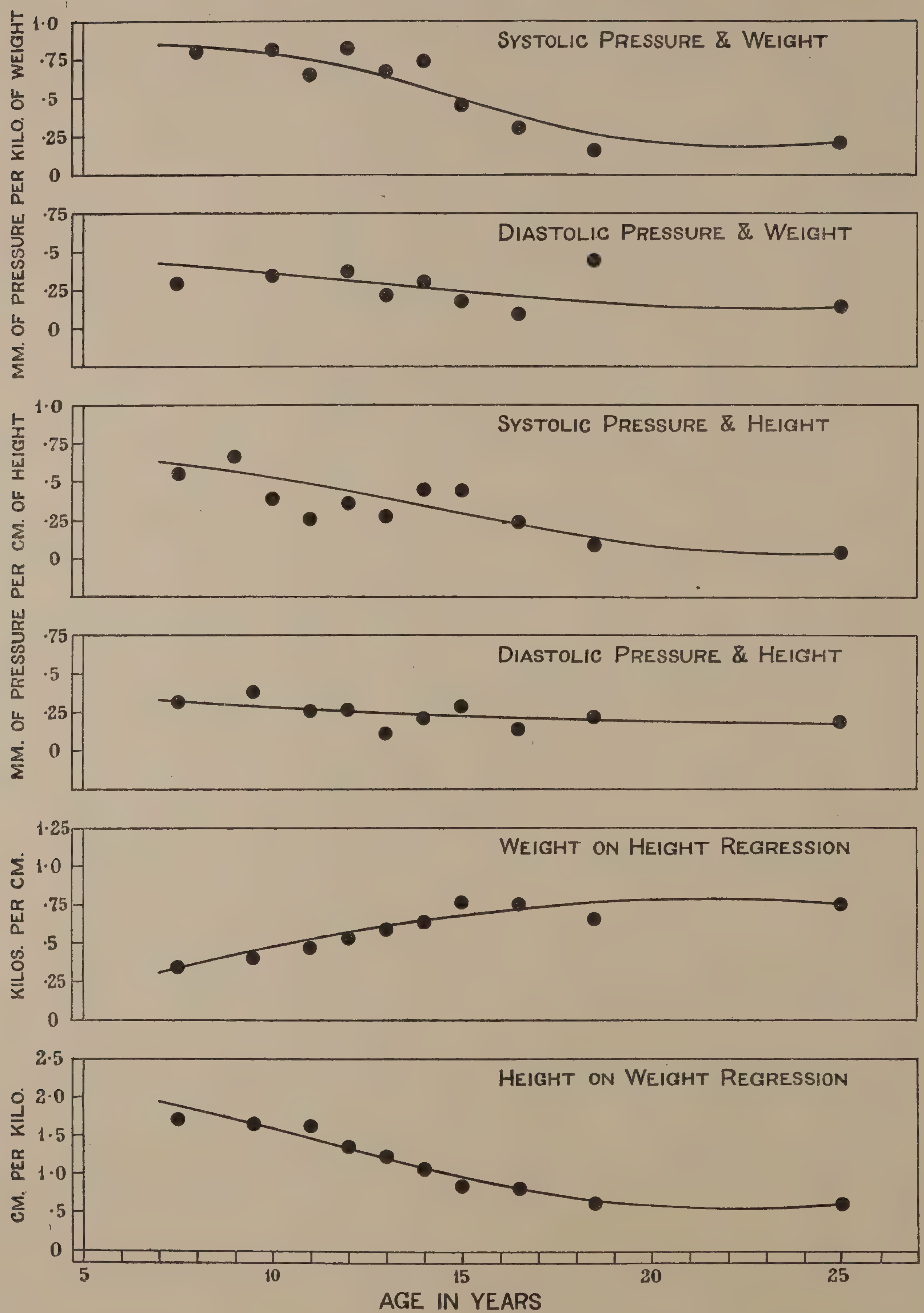


FIG. 16.

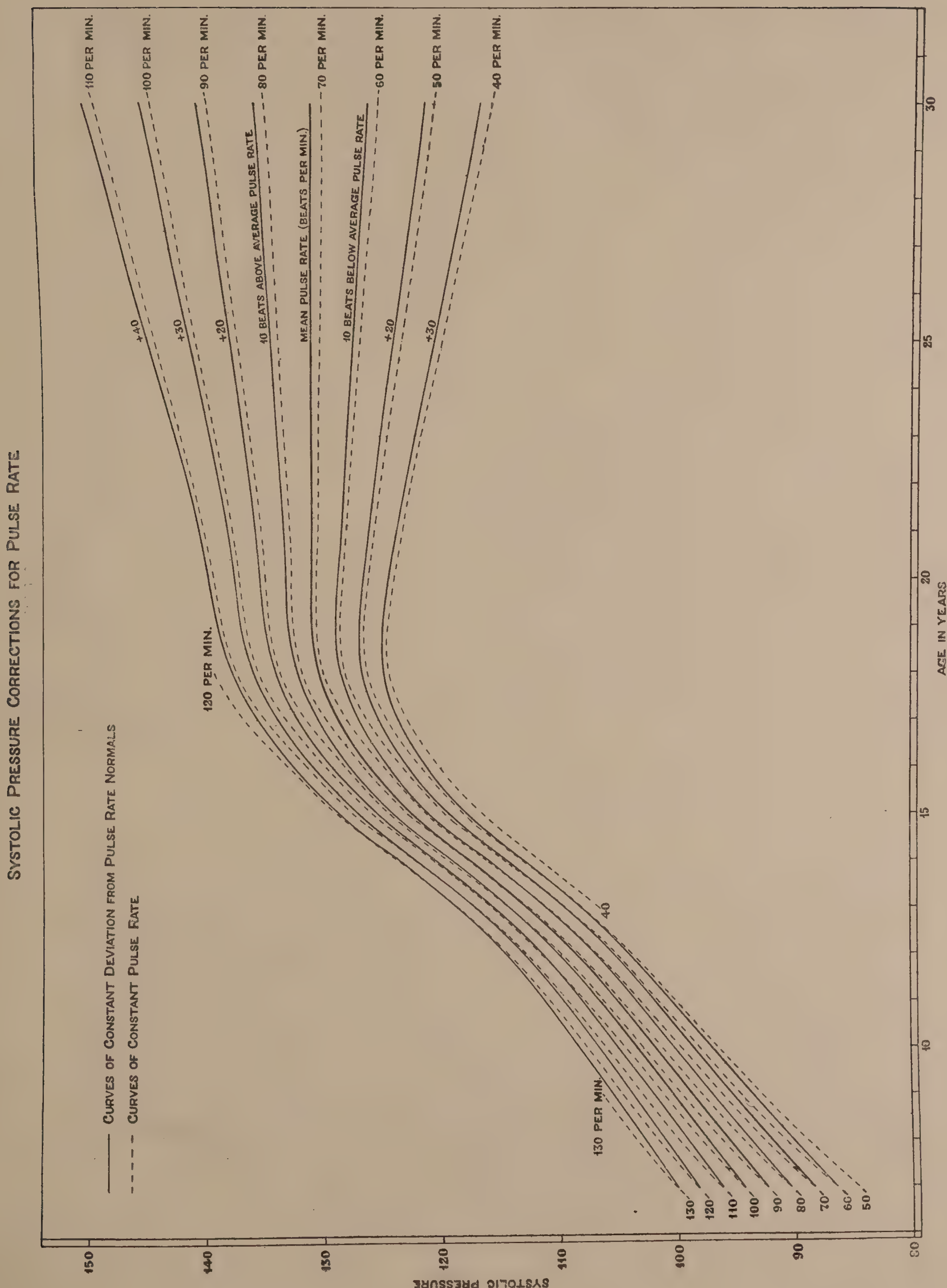
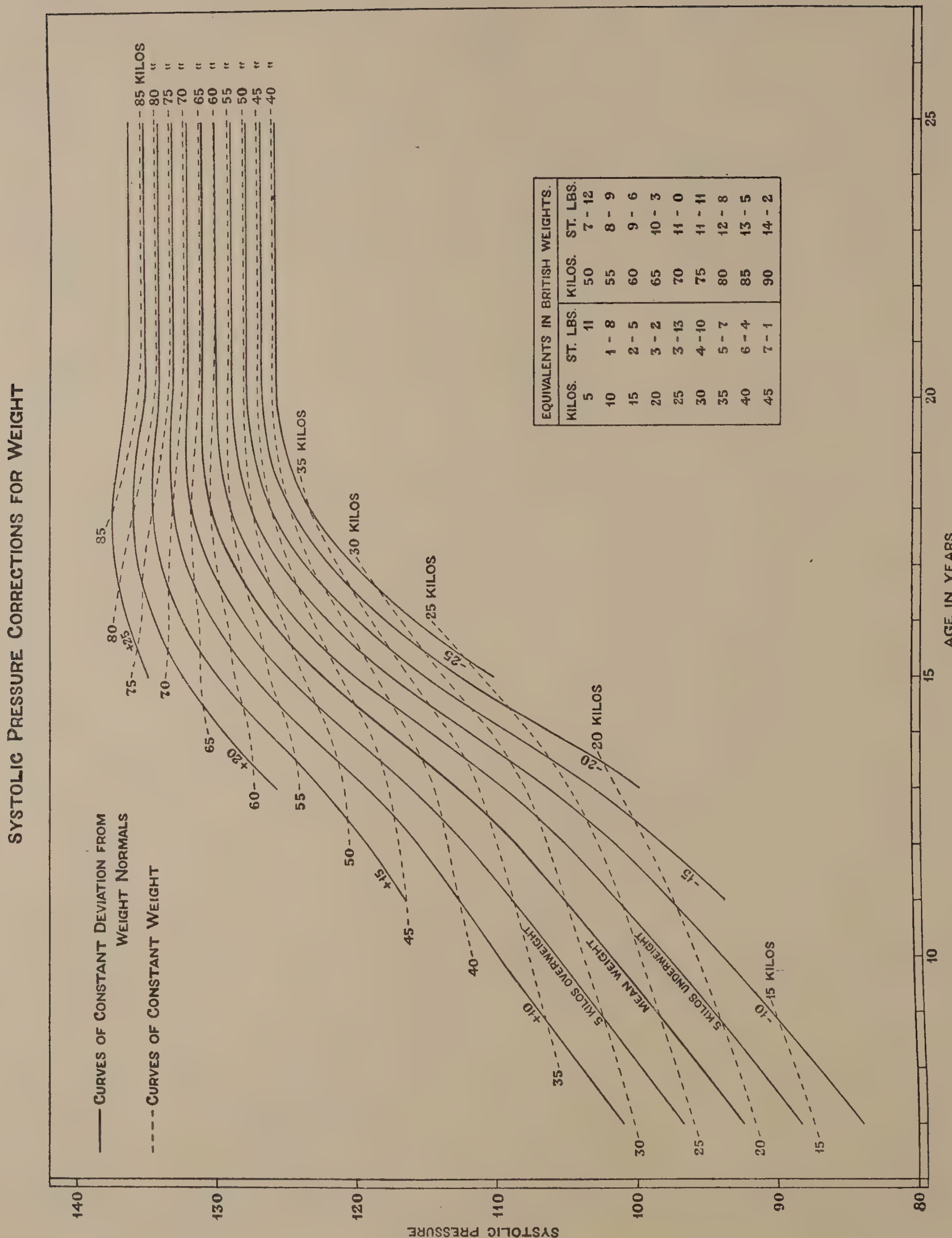

SYSTOLIC PRESSURE CORRECTIONS FOR PULSE RATE
CURVES OF CONSTANT DEVIATION FROM PULSE RATE NORMALS
CURVES OF CONSTANT PULSE RATE
110 PER MIN.
100 PER MIN.
90 PER MIN.
80 PER MIN.
70 PER MIN.
60 PER MIN.
50 PER MIN.
40 PER MIN.
120 PER MIN.
130 PER MIN.
10 BEATS ABOVE AVERAGE PULSE RATE
MEAN PULSE RATE (BEATS PER MIN.)
10 BEATS BELOW AVERAGE PULSE RATE
+40
+30
+20
+20
+30
40
130
120
110
100
90
80
70
60
50
SYSTOLIC PRESSURE
150
140
130
120
110
100
90
80
AGE IN YEARS
10
15
20
25
30

FIG. 17.



EQUIVALENTS IN BRITISH WEIGHTS.			
KILOS.	ST. LBS.	KILOS.	ST. LBS.
5	11	50	7 - 12
10	1 - 8	55	8 - 9
15	2 - 5	60	9 - 6
20	3 - 2	65	10 - 3
25	3 - 13	70	11 - 0
30	4 - 10	75	11 - 11
35	5 - 7	80	12 - 8
40	6 - 4	85	13 - 5
45	7 - 1	90	14 - 2

Fig. 18.

of figures to a diagram, and also in order to combine in a single table the weight and pulse-rate corrections, we have drawn up Table 30. From this table it is possible to rapidly find the systolic pressure average for males of any given age, weight and pulse rate, and also the range of variation about this average which might still be considered as possibly normal. Owing to the very small or zero correlation between weight and pulse rate, the corrections for these two factors can be added or subtracted without appreciable error.

TABLE 30. *For finding the Normal Systolic Pressure for Males of given Age, Weight and Pulse Rate.*

			Age at nearest birthday															
			7	8	9	10	11	12	13	14	15	16	17	18	19	20	25	30
	kgms.	st. lbs.																
Weight	15	2 5	87·4	88·7	90·2	—	—	—	—	—	—	—	—	—	—	—	—	—
	20	3 2	91·7	93·0	94·3	95·9	97·6	99·4	101·5	—	—	—	—	—	—	—	—	—
	25	3 13	96·0	97·2	98·5	99·8	101·4	102·9	104·7	107·5	111·4	114·6	—	—	—	—	—	—
	30	4 10	100·2	101·4	102·6	103·8	105·2	106·4	108·0	110·4	113·8	116·7	119·6	—	—	—	—	—
	35	5 7	—	105·6	106·7	107·8	109·0	110·0	111·2	113·3	116·3	118·8	121·3	123·3	—	—	—	—
	40	6 4	—	—	—	111·8	112·7	113·5	114·4	116·2	118·8	120·8	123·1	124·7	125·6	126·0	125·9	125·9
	45	7 1	—	—	—	—	116·5	117·0	117·6	119·0	121·3	122·9	124·8	126·2	126·8	127·1	126·9	126·9
	50	7 12	—	—	—	—	—	120·5	120·9	121·9	123·7	125·0	126·5	127·6	128·0	128·2	128·0	128·0
	55	8 9	—	—	—	—	—	—	124·1	124·8	126·2	127·1	128·2	129·0	129·2	129·2	129·0	129·0
	60	9 6	—	—	—	—	—	—	127·3	127·7	128·7	129·1	130·0	130·5	130·4	130·2	130·1	130·1
	65	10 3	—	—	—	—	—	—	—	130·5	131·2	131·2	131·7	131·9	131·6	131·2	131·1	131·1
	70	11 0	—	—	—	—	—	—	—	—	133·6	133·3	133·4	133·3	132·8	132·3	132·2	132·2
	75	11 11	—	—	—	—	—	—	—	—	136·1	135·4	135·1	134·7	134·0	133·3	133·3	133·3
	80	12 8	—	—	—	—	—	—	—	—	—	137·5	136·9	136·2	135·2	134·3	134·3	134·3
	85	13 5	—	—	—	—	—	—	—	—	—	—	—	137·6	136·4	135·3	135·4	135·4
	90	14 2	—	—	—	—	—	—	—	—	—	—	—	—	—	136·4	136·4	136·4
Pulse	Average rate		90	87	85	83·5	83	82	81·5	80·5	79	77	74	72	72	72	72	72
	Excess or defect in pulse rate*		5	6	6	6	6	7	7	7	7	6	6	5	5	5	3	2

* Requiring additional pressure correction of 1 mm. of the same sign.
Deviations of 30 mm. or more from the above values are almost certainly pathological, and deviations exceeding 20 mm. should be regarded with suspicion.

To take an example, supposing we have a patient aged $15\frac{1}{4}$, weighing 10 stone or 61 kgms. with a pulse rate 92 and systolic pressure 99 mm.; reading down column 15 we find 128·7 for 60 kgms. and 131·2 for 65, giving by interpolation 130·7 for 64 kgms.; at the foot of the column we note the average pulse rate to be 79, and that 1 mm. must be added for every 7 units in excess of this figure; our excess being $91 - 79 = 12$ we must add $\frac{12}{7}$ or 1·7 mm. to 130·7, giving 132·4 as the average for individuals of the type of our patient. Referring to the note at the foot of the table we conclude that our actual reading of 99 mm., being 33·4 mm. below the average, is almost certainly pathological, being far too low. Actually about 1 in 500 of such individuals might theoretically give such a low reading in a chance distribution, or the odds are about 499 to 1 that our patient is pathological. This example

illustrates the advantage of taking weight and pulse rate into account, for if we consider only the age of our patient and refer to Table 9, we find there that the possible normal range for age 15 is 89—158, and we might therefore conclude that a reading of 99 was not unreasonable, whereas it is really dangerously low for such a heavy boy as our patient.

Turning now to the *diastolic pressure* and following exactly the same process we note (Table 28) that the correlations with weight are small and irregular, being of the order ·15; when height is constant they become mostly zero or slightly negative except at ages 18—19 where there is a large probable error; the average corrected value for r for all ages becomes $-\cdot 01$, and we may therefore safely conclude that the apparent correlations between diastolic pressure and weight are due to the correlations of both variables with height. The actual regressions on weight, however, have been shown in Fig. 16, and the smoothed values fall from ·42 mm. of pressure per kgm. at age 7 to ·16 in adults.

The correlations of diastolic pressure with height are of the order of ·2, and become rather lower as adult age is approached; for weight constant they are irregular but for the most part significantly positive. This dependence of diastolic pressure on height rather than weight is an interesting confirmation of the view that it is a function of the arterial resistance, which must naturally increase with the length of the arteries, other factors being constant. The regressions have been plotted in Fig. 16 and smoothed with a spline curve; they fall from ·33 mm. of pressure per cm. of height at age 7 to about ·2 mm. per cm. in adults.

This correction is small but is possibly worth applying in doubtful cases, and we have therefore constructed Fig. 20, showing (1) curves of diastolic pressure with age for height deviations of 10, 20, 30 and 40 cm. above and below the average, and (2) curves (dotted) of diastolic pressure for constant height. In Table 31 we have also combined the height and pulse-rate corrections, so that the expected diastolic pressure for males of any given age, height and pulse rate can be rapidly read off.

To illustrate the use of this table, let us suppose we are presented with a male patient aged $18\frac{9}{12}$, height 5 ft. 3 in. or 160 cm., pulse rate 61, and diastolic pressure 106 mm.; referring to column 19, for height 160 cm. we find the value 79·4; at the foot of the column we find average pulse rate = 72, and correction to be deducted is $(72-61)/25 = \cdot 4$, giving us the corrected value for diastolic pressure 79 mm. Our patient has therefore an excess of 27 mm. which (see footnote to table) is almost certainly pathological, being too high. Here again we see the advantage of correcting for height and pulse rate in doubtful cases, since if we had considered age alone, according to Table 9 the value 106 would lie within normal limits for age 19.

(7) Race, Social Class, Heredity.

The existence of *racial variations* in blood pressure has already been alluded to. The comparative material is so scanty and the technique used so various that it is of little use attempting to arrive at any conclusion by comparison of the few figures

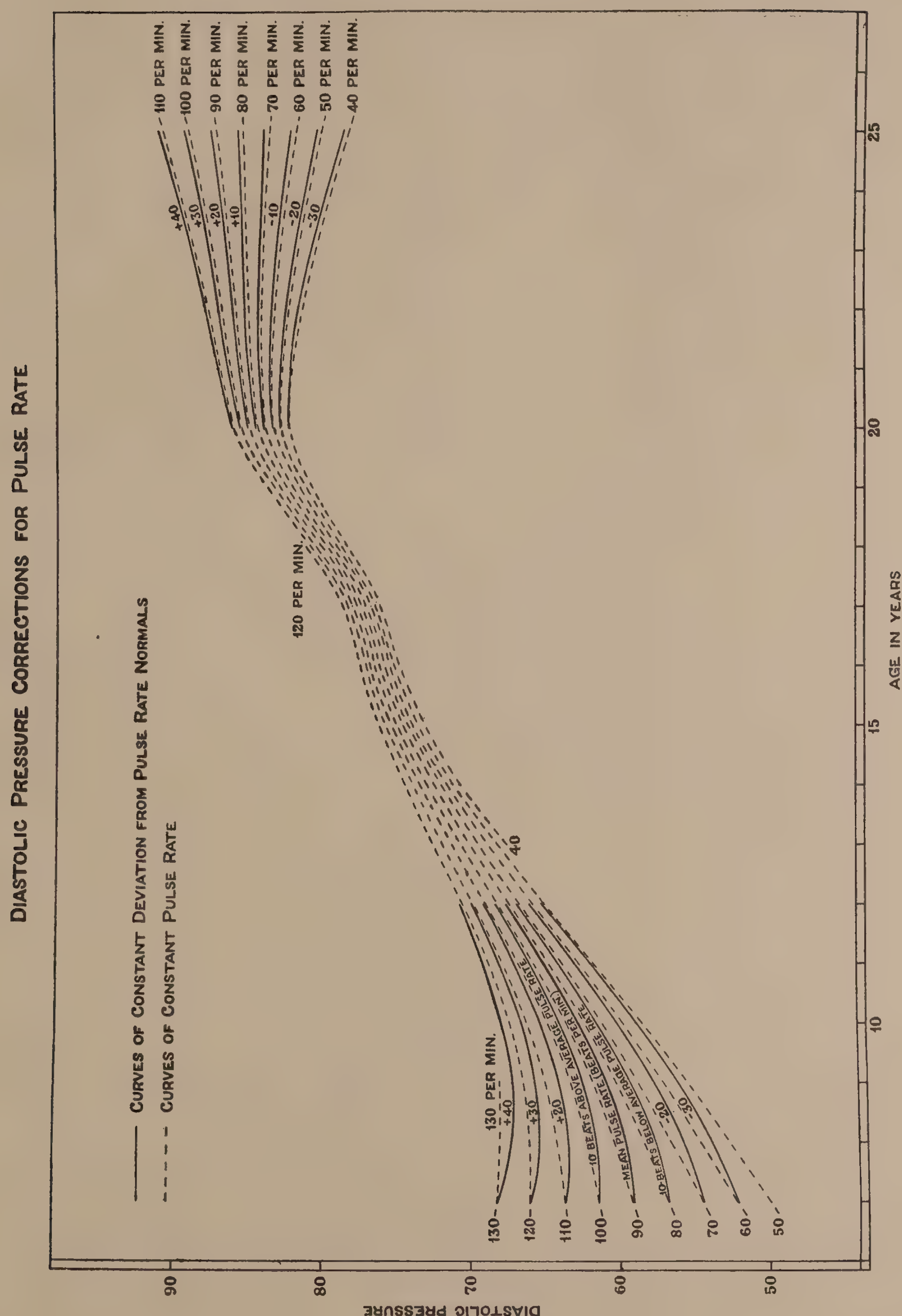
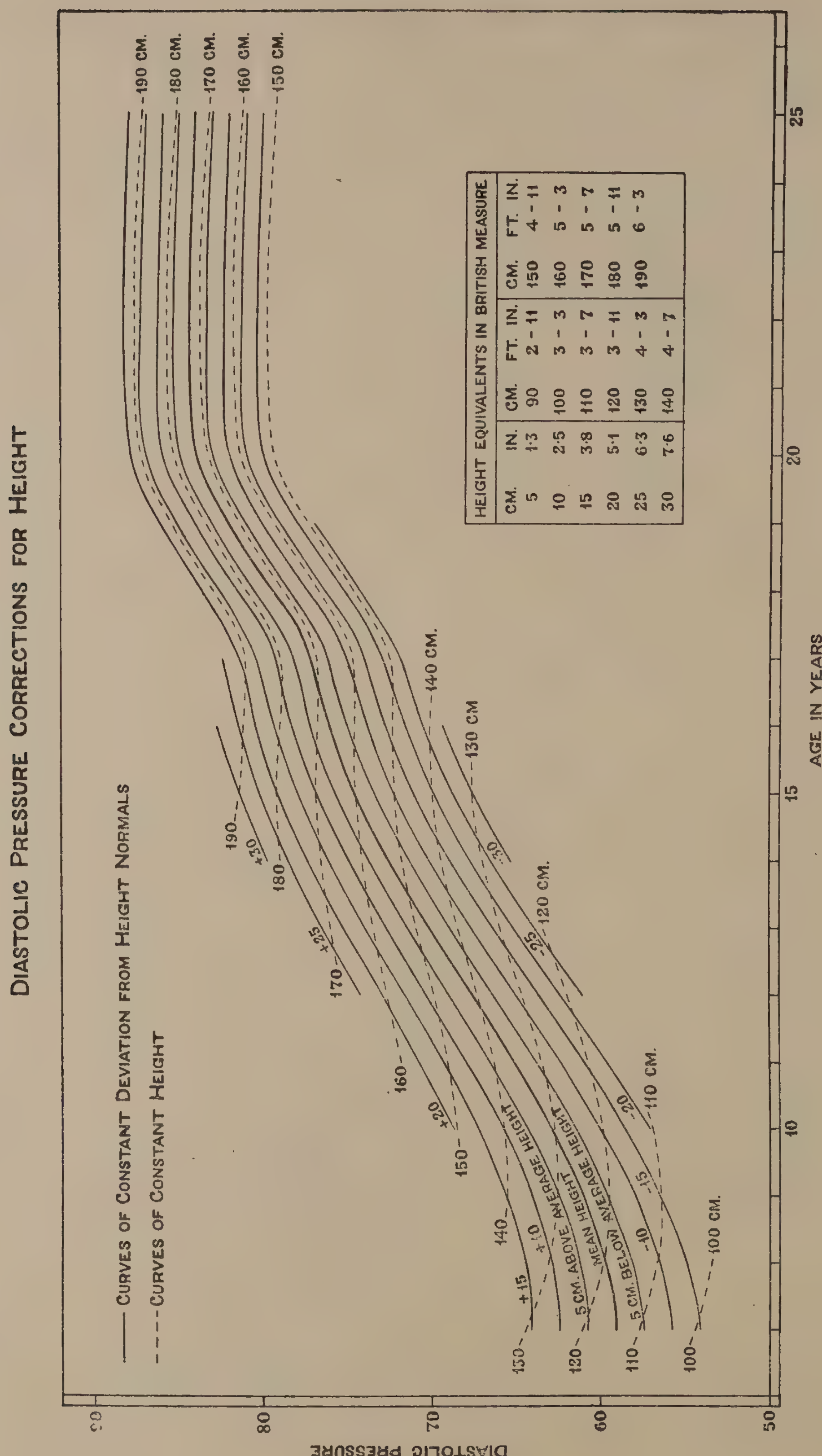

DIASTOLIC PRESSURE CORRECTIONS FOR PULSE RATE
CURVES OF CONSTANT DEVIATION FROM PULSE RATE NORMALS
CURVES OF CONSTANT PULSE RATE
110 PER MIN.
100 PER MIN.
90 PER MIN.
80 PER MIN.
70 PER MIN.
60 PER MIN.
50 PER MIN.
40 PER MIN.
120 PER MIN.
130 PER MIN.
+40
+30
+20
+10
-10
-20
-30
10 BEATS ABOVE AVERAGE PULSE RATE (BEATS PER MIN.)
MEAN PULSE RATE (BEATS PER MIN.)
10 BEATS BELOW AVERAGE PULSE RATE
130
120
110
100
90
80
70
60
50
40
AGE IN YEARS
10
15
20
25
DIASTOLIC PRESSURE
90
80
70
60
50

FIG. 19.



CM.	IN.	CM.	FT. IN.	CM.	FT. IN.
5	1·3	90	2 - 11	150	4 - 11
10	2·5	100	3 - 3	160	5 - 3
15	3·8	110	3 - 7	170	5 - 7
20	5·1	120	3 - 11	180	5 - 11
25	6·3	130	4 - 3	190	6 - 3
30	7·6	140	4 - 7		

FIG. 20.

available. The lower average systolic pressure found in a few observations on Southern races might be accounted for by the combined effects of climate, diet, habits of life and differences in average physical development. In order to test this point we have made a comparison between a few British and foreign students resident in London and attending University College, since presumably the environmental differences are here largely eliminated. The numbers are yet very small, but we give the results here for what they are worth. Our average value for the systolic pressure of 103 British male students between 20—38 years of age (average age 23·1) was 130·3 ± ·8, whilst

TABLE 31. *For finding the Normal Diastolic Pressure for Males of given Age, Height and Pulse Rate.*

	cm.	ft.	in.	Age at nearest birthday: 7	8	9	10	11	12	13	14	15	16	17	18	19	20	25	30	35
Height	100	3	3	54·4	53·4	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	105	3	5	56·1	55·0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	110	3	7	57·8	56·6	56·4	57·0	—	—	—	—	—	—	—	—	—	—	—	—	—
	115	3	9	59·4	58·2	57·9	58·4	—	—	—	—	—	—	—	—	—	—	—	—	—
	120	3	11	61·1	59·8	59·5	59·9	60·8	62·1	63·5	—	—	—	—	—	—	—	—	—	—
	125	4	1	62·8	61·4	61·0	61·3	62·2	63·4	64·7	—	—	—	—	—	—	—	—	—	—
	130	4	3	64·5	63·0	62·5	62·8	63·6	64·7	66·0	67·1	67·7	—	—	—	—	—	—	—	—
	135	4	5	—	—	64·0	64·2	65·0	66·0	67·2	68·3	68·9	—	—	—	—	—	—	—	—
	140	4	7	—	—	65·6	65·7	66·3	67·4	68·5	69·5	70·0	70·2	—	—	—	—	—	—	—
	145	4	9	—	—	—	67·1	67·7	68·7	69·7	70·6	71·2	71·3	—	—	—	—	—	—	—
	150	4	11	—	—	—	68·6	69·1	70·0	71·0	71·8	72·3	72·4	72·6	74·7	77·4	79·4	79·3	77·2	73·4
	155	5	1	—	—	—	—	70·4	71·3	72·3	73·0	73·5	73·5	73·6	75·7	78·4	80·4	80·2	78·1	74·3
	160	5	3	—	—	—	—	71·8	72·6	73·5	74·2	74·6	74·6	74·7	76·8	79·4	81·4	81·2	79·1	75·3
	165	5	5	—	—	—	—	—	—	74·8	75·4	75·7	75·7	75·8	77·8	80·4	82·3	82·2	80·1	76·3
	170	5	7	—	—	—	—	—	—	76·0	76·6	76·8	76·8	76·9	78·8	81·4	83·3	83·2	81·1	77·3
	175	5	9	—	—	—	—	—	—	—	77·8	78·0	77·9	78·0	78·9	82·4	84·3	84·2	82·1	78·3
	180	5	11	—	—	—	—	—	—	—	79·0	79·1	79·0	79·0	80·9	83·4	85·3	85·2	83·1	79·3
	185	6	1	—	—	—	—	—	—	—	—	80·3	80·1	80·1	81·9	84·4	86·3	86·1	84·1	80·3
	190	6	3	—	—	—	—	—	—	—	—	81·4	81·2	81·1	83·0	85·4	87·3	87·1	85·1	81·2
Pulse	Average rate			90	87	85	83·5	83	82	81·5	80·5	79	77	74	72	72	72	72	72	72
	Excess or defect in pulse rate*			4	5	6	8	10	12	16	20	25	30	30	30	25	20	6	6	6

* Requiring additional pressure correction of 1 mm. of the same sign.
Deviations of 24 mm. or more from the above values are almost certainly pathological, and deviations exceeding 16 mm. should be regarded with suspicion.

for 30 students of other races, ages 20—38 (average age 23·7), the mean systolic pressure was 118·8. Of these, 14 were of Indian parentage, giving a mean systolic pressure 118·7, diastolic pressure 80·8, pulse pressure 38·5, pulse rate 74·0, and cardiac energy product 2869. The corresponding values for British students were 130·3, 84·8, 45·5, 70·2, and 3264. The figures are shown more clearly in Table 32. The apparent differences in systolic pressure are much too great to be accounted for by the smaller physical development and differences in pulse rate, which would only account for a deficiency of ·5 mm. in the case of the Indian students, and

a deficiency of 1·4 mm. for the group of European students. The expected mean values obtained by applying the corrections in Tables 30 and 31 to the age, weight, height and pulse rate of each individual in the group are given in brackets in the table. The group of European students consisted of Poles, Germans, Italians, Russians, Portuguese and others. The diastolic pressure averages show a much smaller deficiency, which is hardly significant after allowing for the physical development factor. It therefore appears that the racial difference, if a real one, depends chiefly on the pulse pressure, the average values for this being $45 \cdot 5 \pm \cdot 7$ for British students as compared with $37 \cdot 4 \pm 1 \cdot 2$ for other races. The mean values for the "cardiac output" product also appear to be considerably lower (see Table 32). These results seem to show a higher level of systolic and pulse pressures, and possibly of diastolic pressure in British as compared with more Southern races, but this of course requires substantiating by more measurements.

TABLE 32. *Comparison of Blood Pressures of British Male students with a few Male students of other Races* (*Ages* 20—38).

	No.	Mean age	Mean weight	Mean height	Mean pulse rate	Mean systolic pressure	Mean diastolic pressure	Mean pulse pressure	Mean cardiac energy product
British students	103	23·1	63·4	174·2	70·2	130·3 ± ·8	84·8 ± ·5	45·5 ± ·7	3264 ± 67
Indian and Singhalese	14	22·6	56·1	166·2	74·0	118·7 ± 1·8 (129·8)	80·8 ± 1·2 (83·1)	38·5 ± 1·7	2869 ± 160
European	16	24·7	61·8	169·8	68·0	119·0 ± 1·7 (128·9)	82·5 ± 1·1 (82·5)	36·5 ± 1·4	2502 ± 150
All foreign students	30	23·7	59·2	167·8	71·1	118·8 ± 1·3 (129·7)	81·7 ± ·9 (82·6)	37·4 ± 1·2	2675 ± 110

N.B. Figures in brackets are the values expected by applying the corrections in Tables 30, 31 to these groups.

In view of these figures we have for the purposes of this research only included British students in any of the foregoing tables or calculations.

As regards *social class*, there are, as far as we know, no data to show how this may affect blood pressure. That it is nevertheless an important factor was brought home to us very early in this research. In our school investigations we have been dealing with very different social classes. With one exception all the Elementary Schools we have visited have been in poor class districts of London, though by no means in the worst areas. In the following discussion we shall refer to this social group as Group III. The one exception was situated in a residential district of N.W. London, and we have included this school along with our Secondary Schools in Group II. The Secondary Schools we visited were for the most part situated in suburban areas, and presented a very remarkable difference in average social grade to Group III. Though it is popularly believed that Secondary Schools are peopled chiefly by the brightest boys from the Elementary Schools, this is certainly the case

only to a very limited extent, and one doubts whether in many Secondary Schools more than 10 °/。 have ever been in Elementary Schools. The difference is chiefly one of social grading, and below the age of 12 almost entirely so; from 11 onwards a certain amount of dilution takes place by boys coming from Elementary Schools, but after 15 the factor of selection is again at work, since the boys in the best circumstances tend to remain at school longest. This factor of selection operating at the lower end of the Secondary School age range led to some puzzling results in the first instance; thus it will be seen from Fig. 5 that from age 9 to 13 there is apparently a very slow rise (about 1 mm. per annum) in the systolic pressure of our Secondary School boys, this being probably due to the increasing selection in the admission of younger boys to these schools. The same effect is also noticeable in the diastolic and pulse-pressure curves (Figs. 6, 7). Most of our boys of age 8 belonged to the Elementary School we have referred to as being included in Group II—the selective factor would not here be so operative, hence the sudden drop in this case.

Group I consists of boys of the Merchant Taylors' School and students of University College, who naturally come from a higher average social grade than the other groups. They are shown separately for ages 17 to 24 in the age curves.

The mean weights, heights, pulse rates and blood-pressure variables for these three social groups are given in Table 33 at various ages. At ages 15 and 16 all the boys belonged to Group II. In the adult group we have also separated 22 factory workers (not including the clerical staff of the Factory) for comparison with the college students.

If we examine Table 33 in detail as regards:

(i) *Weight.* There is an average difference of 1·6 kgms. between Groups II and III and about 3 kgms. between Groups I and II, the higher group being always superior; the factory workers are also 2·2 kgms. inferior to the average for college students. See Fig. 14.

(ii) *Height.* There is an average difference of 3·5 cm. in height between Groups II and III, the former being always superior at age 13. Group I is also superior to II at ages 17—18, and college students to factory workers by 2—3 cm. See Fig. 15.

(iii) *Pulse Rate.* Except for age 8 the average pulse rate for Secondary School boys is considerably higher than for Elementary Schools, and for age 13 this difference amounted to 10 beats per minute. No doubt this was partly due to the somewhat different conditions under which the boys were examined in the two types of school, since for the most part the boys in Group II were undergoing a routine medical test in the same room, which was not always the case in Group III, but we cannot believe that this accounts for such a considerable difference, which averages 5·5 per minute for all ages. When we turn to ages 17—18 we notice that Group I had much slower pulses than Group II, whereas between factory workers and college students there was little difference. We cannot therefore draw any safe conclusions as to the effect of Social Class on pulse rate. (See also Fig. 11.)

(iv) *Systolic Pressure.* Table 33 and Fig. 5 show a considerable divergence of the values for Groups II and III below 13, and at every age the latter group has lower pressures. Group I was also superior to Group II by some 4 mm.

TABLE 33. *Influence of Social Class on Blood Pressure (Males).*

Age centred at	Class	No. of cases	Weight kgms.	Height cms.	Pulse rate	Systolic pressure	Diastolic pressure	Pulse pressure	Pulse rate × pressure
	Secondary Schools ...	31	24·30 ± ·38	122·55 ± ·64	85·64 ± 1·56	100·40 ± 1·40	61·93 ± ·93	39·07 ± 1·02	3375 ± 120
8	Elementary Schools	38	23·37 ± ·34	121·34 ± ·58	88·52 ± 1·38	93·92 ± 1·26	57·73 ± ·82	36·17 ± ·90	3284 ± 107
	Difference		·93	1·21	−2·88	6·48 (·27)	4·20 (−·20)	2·90	91
	Secondary Schools ...	10	28·35 ± ·57	134·75 ± 1·15	91·75 ± 2·98	108·30 ± 2·31	68·16 ± 2·24	41·83 ± 2·16	3625 ± 182
9½	Elementary Schools	148	25·97 ± ·20	125·87 ± ·39	82·83 ± ·51	99·30 ± ·54	62·22 ± ·48	37·22 ± ·53	3141 ± 51
	Difference		2·38	8·88	8·92	9·00 (3·49)	5·94 (3·91)	4·61	484
	Secondary Schools ...	40	31·45 ± ·51	138·35 ± ·82	84·35 ± 1·23	109·00 ± 1·27	68·61 ± ·79	40·94 ± 1·26	3400 ± 112
11	Elementary Schools	35	29·55 ± ·56	133·90 ± ·91	78·19 ± 1·20	102·13 ± 1·35	61·38 ± ·92	41·50 ± 1 14	3148 ± 103
	Difference		1·90	4·45	6·16	6·87 (2·38)	7·23 (1·67)	−·56	252
	Secondary Schools ...	95	34·35 ± ·35	142·00 ± ·54	83·81 ± ·80	110·70 ± ·88	70·24 ± ·59	42·57 ± ·83	3630 ± 86
12	Elementary Schools	48	31·53 ± ·49	137·39 ± ·76	77·82 ± 1·01	105·50 ± 1·24	63·19 ± ·87	42·55 ± 1·10	3165 ± 109
	Difference		2·82	4·61	5·99	5·20 (2·88)	7·05 (1·68)	·02	465
	Secondary Schools ...	84	36·99 ± ·37	146·35 ± ·54	85·72 ± ·98	111·50 ± ·93	70·18 ± ·63	41·92 ± ·89	3626 ± 88
13	Elementary Schools	56	36·39 ± ·61	147·78 ± ·88	75·74 ± 1·20	110·24 ± 1·19	69·19 ± ·80	40·63 ± 1·12	3023 ± 111
	Difference		·60	−1·43	9·98	1·26 (5·35)	·99 (·25)	1·29	603
13·75	Secondary Schools ...	49	42·09 ± ·65	152·81 ± ·90	83·64 ± 1·22	115·25 ± 1·23	74·08 ± ·85	41·83 ± 1·12	3552 ± 109
(13½—14)	Elementary Schools	66	40·09 ± ·68	149·38 ± ·95	79·77 ± 1·04	113·10 ± 1·06	70·06 ± ·74	43·99 ± ·97	3517 ± 94
	Difference		2·00	3·43	3·87	2·15 (1·94)	4·02 (1·02)	−2·16	35
	Public School ...	47	59·10 ± ·76	171·92 ± ·79	68·71 ± 1·07	130·78 ± 1·28	77·42 ± ·89	53·36 ± 1·38	3732 ± 121
17	Secondary Schools ...	29	56·70 ± ·97	171·37 ± 1·00	76·23 ± 1·36	126·20 ± 1·63	74·04 ± 1·13	52·39 ± 1·76	3795 ± 154
	Difference		2·40	·55	−7·52	4·58 (−·45)	3·38 (−·12)	·97	−63
	Public School ...	20	61·85 ± ·94	175·35 ± ·87	63·95 ± 2·42	131·50 ± 1·59	78·70 ± 1·19	52·80 ± 1·67	3300 ± 187
18	Secondary Schools ...	18	57·84 ± ·99	172·16 ± ·91	78·73 ± 2·55	127·51 ± 1·67	75·72 ± 1·25	51·79 ± 1·76	4138 ± 197
	Difference		4·01	3·19	−14·78	3·99 (−1·56)	2·98 (−·15)	1·01	−838
20—39	Students	107	64·16 ± ·45	174·04 ± ·39	70·79 ± ·82	130·13 ± ·79	83·92 ± ·55	45·69 ± ·71	3295 ± 64
	Factory workers* ...	22	61·95 ± ·98	170·86 ± ·85	69·90 ± 1·80	134·77 ± 1·75	80·74 ± 1·21	52·50 ± 1·57	3662 ± 140

* Measured during work.

The bracketed figures give the differences to be expected between the groups on the basis of Tables 30 and 31.

In order to determine whether this is accounted for by the superior weight and different pulse rate of the higher group, the mean expected systolic pressure of all the individuals comprising each group has been calculated by aid of Table 30, and the differences to be expected between the group means on this basis are given in brackets at each age. It will be noticed that at every age except 13 and 13·75 there is still a considerable residual excess of systolic pressure not accounted for in this way. Thus the average observed difference between Groups II and III is 6·2 mm., whilst the average expected difference is 3·1 mm.; for Groups I and II the excess averages 4·3 mm. whereas a deficiency of 1 mm. should be expected owing to slower pulse. It seems clear therefore that social class apart from body weight, and therefore presumably apart from nutrition as usually judged, and also apart from pulse-rate differences, has a definite influence on the systolic pressure. No doubt this partly operates through heredity, but it may also be due to differences in diet, since a diet containing much animal protein almost certainly tends to produce a higher pressure than a more vegetable diet, though body weight and nutrition may not be affected to the same extent.

We have not mentioned the figures for our small group of factory workers, which show an excess of 4·6 mm. over college students; we do not consider that any useful conclusion can be drawn from this result as regards social class, since the factory hands were taken straight from manual work to be measured, which would be sufficient to account for their higher pressures.

(v) *Diastolic Pressure.* The differences here are similar to those found for systolic pressure, the higher social class being always superior (see Fig. 6). The expected differences on the basis of the heights and pulse rates of the individuals comprising the groups are shown in brackets. The average observed difference between Groups II and III is 5·9 mm., whilst the average expected difference is only 1·4 mm., leaving 4·5 mm. not accounted for by differences in physique and pulse rate. Between Groups I and II the average excess is 3·1 mm. instead of an expected deficiency of ·13 mm.

It is therefore evident that social class affects the systolic and diastolic pressures to very much the same extent. As regards the factory workers they also show a lower diastolic pressure than college students, partly no doubt for the reasons we have already stated.

(vi) *Pulse Pressure.* These differences are not so constant, but on the whole the pulse pressure tends to be slightly higher for the superior class (see Table 33 and Fig. 7). In the case of the factory workers there is a very large excess of pulse pressure, owing, as we have noted, to the fact that they were engaged in manual work at the time.

The differences in pulse pressure × pulse rate product are also rather obscure, Group II being superior both to Groups III and I.

(vii) *Heredity* is undoubtedly of importance in the case of blood pressure as in other individual characters.

Oliver (40) states that "in certain families heredity plays a part in inducing higher or lower ranges of arterial pressure." Dana (44) concludes that hereditary hypertension is common, and that in these cases it may not necessarily give rise to patho-

logical symptoms. Thus he quotes the case of a father and two sons (all past middle age) with systolic pressures in the neighbourhood of 200 mm. Warfield (45) divides cases of chronic hypertension into three types, one being the "hereditary type," which includes the "florid, robust, exuberantly healthy people." Alvarez (46) also maintains that a certain proportion of the population inherits a tendency to develop arterial hypertension. There is undoubtedly room for research on this question.

(8) Muscular Strength.

In order to test whether muscular strength apart from physical development has any relation with blood pressure, we measured the hand grip of some 600 of our cases,

Table 34. *Distribution of Total Hand grip with Age* (*Secondary School Boys and Male Students*).

	Age: Centred at																		
Total Hand grip* — Kilos.	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25—29	30—34	Totals
36— 53	—	1	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2
54— 71	2	3	5	—	2	1	—	—	—	—	—	—	—	—	—	—	—	13
72— 89	3	7	20	18	9	2	—	—	—	—	—	—	—	—	—	—	—	59
90—107	1	15	30	16	19	3	1	—	—	—	—	—	—	—	—	—	—	85
108—125	1	8	22	28	29	7	—	—	—	—	—	—	—	—	—	—	—	95
126—143	—	4	12	15	28	17	2	1	—	—	—	—	—	—	—	—	—	79
144—161	—	—	4	9	21	22	1	1	—	3	—	—	2	—	1	—	—	64
162—179	—	—	1	4	10	18	5	—	—	—	1	1	—	—	—	—	—	40
180—197	—	—	—	—	10	9	4	2	—	1	2	3	1	—	—	—	—	32
198—215	—	—	—	—	—	7	7	3	4	2	1	3	1	1	1	—	—	30
216—233	—	—	—	—	1	7	4	1	—	1	5	2	—	2	5	4	2	34
234—251	—	—	—	—	—	3	3	2	—	5	2	1	3	2	1	4	2	28
252—269	—	—	—	—	—	2	—	—	—	2	3	2	—	4	2	3	—	18
270—287	—	—	—	—	—	—	—	2	1	2	5	1	1	1	1	1	1	16
288—305	—	—	—	—	—	—	—	—	—	—	—	—	1	2	1	—	2	6
306—323	—	—	—	—	—	—	—	—	—	1	1	—	—	1	1	—	—	4
324—341	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	1
342—359	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	—	2
360—377	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1
Totals	7	38	95	90	129	98	27	12	5	17	21	14	9	14	13	13	7	609

* Total of 6 readings of dynamometer (kilos.) consisting of three trials with right hand and three with left; readings being taken to the nearest kgm., the intervals are 35·5—53·5, 53·5—71·5, etc.

and applied a muscular fatigue test to 110 male students (British). The *hand grip* was measured by means of an elliptical dynamometer, three trials being allowed with the left hand, followed by three with the right, the total of the six readings being then taken as a measure of the strength of grip for purposes of correlating with other factors. The distribution of total hand grip with age is shown in Table 34, the means for each age, and for each hand separately are given in Table 35, and the relation with age is also shown in Fig. 21.

It will be seen from Table 35 that 66 out of 484 boys up to 16 (13·6 °/。) had a stronger mean grip with the left than the right hand. The highest percentages of

TABLE 35. *Strength of Grip at different Ages (Males).*

Age centred at	No. of cases	Mean total of 3 grips		Mean total for both hands	Standard deviation	Coefficient of variation	Cases stronger in L. than R.	
		R. hand	L. hand				No.	Per cent.
10	7	42	41	83·07 ± 2·62	10·26	12·35	3	42·8
11	38	52	46	98·50 ± 2·23	20·40	20·72	4	10·5
12	95	55	49	103·99 ± 1·59	22·93	22·05	8	8·4
13	90	61	54	115·10 ± 1·74	24·52	21·30	9	10·0
14	129	69	62	130·87 ± 1·86	31·25	23·89	21	16·3
15	98	86	77	163·34 ± 2·69	39·41	24·13	17	17·3
16	27	101	91	192·50 ± 4·51	34·75	18·05	4	14·8
17	12	113	99	212·50 ± 7·48	38·41	18·07	0	0
18	5	116	108	224·00 ± 8·75	29·02	12·96	1	20·0
19	17	123	112	235·41 ± 7·71	47·10	20·01	3	17·6
20—24	71	129	114	243·86 ± 3·54	44·17	18·11	6	8·9
25—29	13	134	118	252·19 ± 5·95	31·78	12·52	3	23·0
30—34	7	138	118	255·71 ± 8·10			1	14·3
TOTAL...	609	—	—	—	—	—	80	13·1

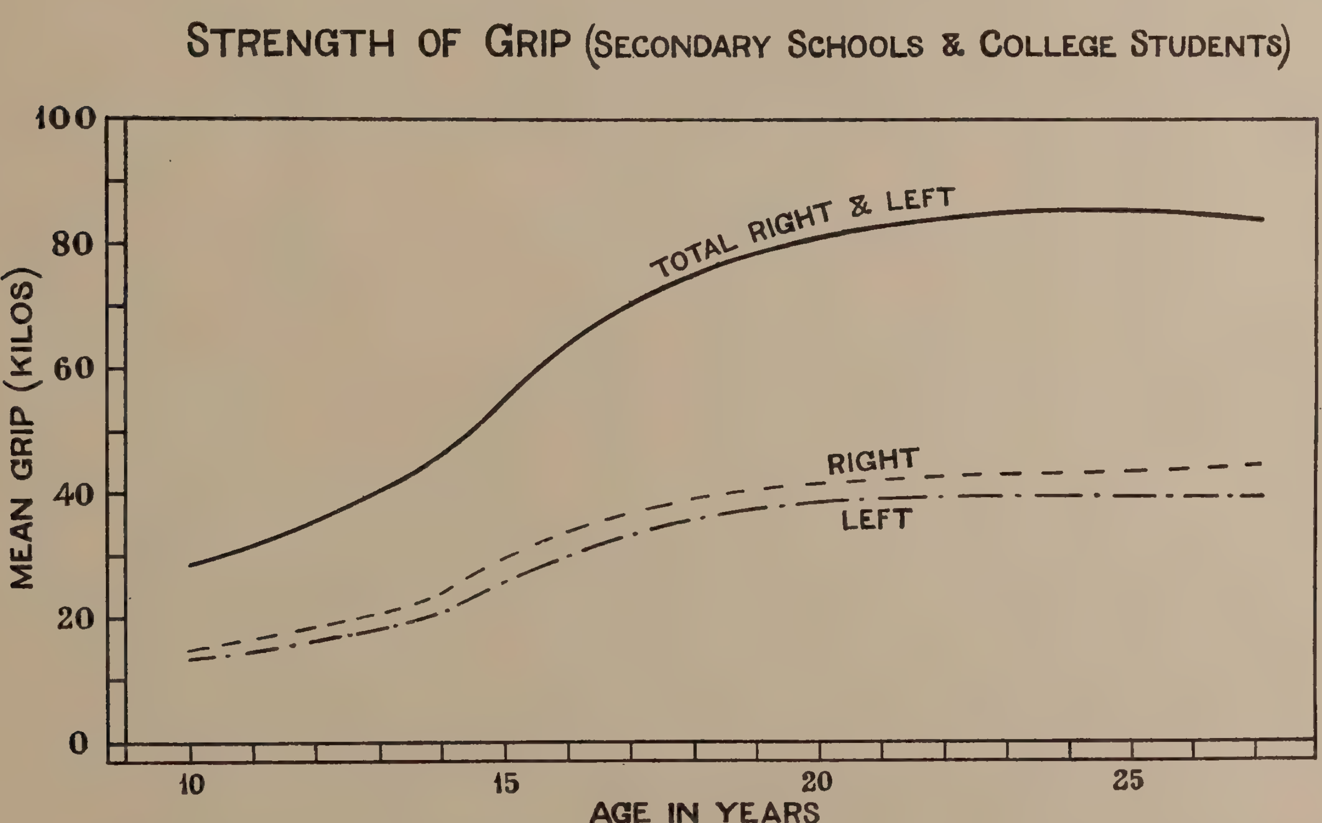


FIG. 21.

left-handedness in this respect (apart from age 10 where the numbers were small) occurred at ages 14 and 15, in which group 38 of 227 boys, or 17 °/₀, were stronger in the left hand. The form of the curve is similar to the physical growth curves, the rate of increase being accentuated between 14 and 17, reaching a fairly uniform adult level at about 19.

The correlation coefficients of mean hand grip with pulse rate, weight, height and blood pressure are shown in Table 36, where the three age groups 11—13, 14—19 and 20—34 have been treated separately. The variables have been corrected for age directly from the age curves in every case. It will be seen from this table that the correlation with the pulse rate is insignificant except in adults (+·15). With weight (corrected for age) it is moderately high at all ages, but after correcting for height

TABLE 36. *Correlations between Hand grip and other Variables.*

Hand grip with	Age period	Corrected for age from curves	Corrected for age and weight	Corrected for age and height	Corrected for age, weight and height
Pulse rate	11—13	– ·098 ± ·044	—	—	—
	14—19	·086 ± ·041	—	—	—
	20—34	·148 ± ·070	—	—	—
Weight...	11—13	·516 ± ·033	—	·000	—
	14—19	·689 ± ·021	—	·413	—
	20—34	·456 ± ·055	—	·298	—
Height	11—13	·624 ± ·028	·410	—	—
	14—19	·620 ± ·025	·170	—	—
	20—34	·376 ± ·061	·106	—	—
Systolic pressure ...	11—13	·090 ± ·044	– ·090	—	– ·054
	14—19	·352 ± ·035	·171	—	·160
	20—34	·342 ± ·063	·330	—	·330
Diastolic pressure	11—13	·077 ± ·046	·035	—	·041
	14—19	·135 ± ·033	·060	—	·040
	20—34	·165 ± ·069	·123	—	·125
Pulse pressure ...	11—13	– ·068 ± ·046	– ·211	—	– 139
	14—19	·226 ± ·039	·129	—	·136
	20—34	·283 ± ·065	·290	—	·291

becomes zero for young boys, ·4 for adolescents and ·3 for adults. The correlations with height are of the same order as for weight, but when weight is constant these become ·41 for young boys, ·17 for adolescents, and ·11 for adults. It is evident, therefore, that height is all-important in young boys, this being due no doubt to the fact that in using a full-sized instrument the size of the hand is the chief factor in the case of small boys, the muscular strength being secondary. In adolescents, however, and also in adults, muscular development, as measured by weight, is of more importance than size of hand, as measured by height, which is highly correlated with it. It is not surprising therefore to find that the correlations with blood pressure are insignificant in the case of young boys. In adolescents, however, there is an initial correlation of ·35 with systolic pressure, reduced to ·16 after correcting for weight

and height; a small correlation of ·13 with diastolic pressure, which becomes insignificant after correction; and with pulse pressure a correlation of ·23, which is reduced to ·14 on correction. In adults the corrected coefficients are all higher than in adolescents, being ·33 with systolic, ·12 with diastolic, and ·29 with pulse pressure. Hence we must conclude that, *apart from physical development, there is a considerable positive dependence of muscular strength on blood pressure, or that they are to some extent dependent on a common factor.*

The *muscular fatigue test* consisted in measuring the maximum upward pull which could be exerted over a period of 30 seconds by each arm in turn in the standing posture. The handle of the dynamometer was adjusted to the level of the elbow, gripped by the hand with palm uppermost, and an upward pull from the floor exerted by the flexor muscles of the forearm. Readings were taken at 5-second intervals for 30 seconds, the total of the seven readings for right and left arms (14 in all) being taken as the measure of total strength. Other muscles than those of the arms are of course involved to some extent in this test. These measurements were made by Mr E. S. Pearson in the Anthropometric Laboratory at University College.

TABLE 37. *Correlations between Efficiency of Muscular Pull and other Variables.* (110 *Males, aged* 18—34.)

	Corrected for age	Corrected for age and weight	Corrected for age, weight and height
Height	·236 ± ·061	– ·003	—
Weight	·363 ± ·056	—	—
Systolic Pressure ...	·174 ± ·063	·149	·149
Diastolic Pressure ...	·164 ± ·063	·138	·138
Pulse Pressure ...	·075 ± ·064	·057	·057
P. P. × P. R.	·150 ± ·063	·158	·158

Since the body weight and some of the pressure variables do not reach a steady level before 20, we have corrected all readings from the age curves before correlating. The coefficients between muscular efficiency as measured by this test and weight, and the blood-pressure variables, are given in Table 37.

It is evident again from these figures that there is, after correcting for weight and height, a small correlation of the order of ·15 between muscular endurance and systolic and diastolic pressures, and also with the pulse pressure rate product, but not with pulse pressure alone.

The only published data bearing on this question of which we are aware are some experiments of Barach and Marks (3), who calculated the "physical efficiency" of 340 young males by means of a formula including strength of back, legs and arms, body weight, vital capacity and gymnastic efficiency. After grouping their cases and finding the mean blood pressure of the groups they concluded that there was no evident relation with systolic pressure. We find, however, that their data actually yield a correlation of about ·21.

(9) Habits of Life, Bodily Fitness, recent Physical Exertion.

Somewhat closely related to the question of muscular strength is the effect of physical exertion and athletic habits of life generally upon the blood pressure.

Graüpner(60) found that moderate physical work in strong persons caused no change in systolic pressure after ceasing work: more severe exertion caused a temporary rise; and very severe exertion caused a temporary fall followed by a rise; he concluded that a subnormal blood pressure following exertion without the subsequent supernormal phase indicated cardiac weakness. Barringer(61) carried out some experiments on normal subjects with a cycle ergometer, and found a rise of systolic pressure to commence some 10 to 15 seconds after cessation of moderate physical work, but if the work was very heavy this rise was delayed and did not commence till 40—50 seconds after ceasing. In subjects of poor physique this delayed rise occurred after only moderate work, and physical training rapidly increased the amount of work which could be performed without causing this delay in the pressure reaction. Rapport(62) also demonstrated the rise in blood pressure after lifting weights, and his curves show that the normal is usually regained within 5 minutes of ceasing work. Smythe(52) measured the blood pressures of 100 cadets before and after 50 minutes' physical training, and concluded that the diastolic pressure was unaltered, whilst the average pulse pressure was slightly lowered after exercise. These measurements, however, were taken 10 minutes after cessation of work. Faught(30) states that sudden severe exertion may cause the systolic pressure to rise by as much as 50 mm., and that moderate and prolonged exercise such as walking raises the systolic pressure by 5—15 mm. whilst the exercise is proceeding.

We have not attempted in this investigation to deal with the immediate effects of exertion on the blood pressure, but were rather concerned to find whether any connection could be traced between blood pressure in growing boys and the extent of their devotion to athletics. As we found that questions addressed to the boys themselves did not enable us to satisfactorily estimate this last factor, we submitted to the Headmasters of several of the Secondary Schools we visited lists of the boys examined with the request that they might be grouped into one of the following five classes:

(1) Very keen on outdoor games, and has played in one or other of the school teams, or has won distinctions in athletic sports or swimming.
(2) Though not in Class (1), devotes more than average attention to games, athletics or swimming.
(3) Takes only a moderate part in these activities.
(4) Takes less than an average part in athletics, but does not avoid them entirely.
(5) Never plays in any organized school games or takes any part in sports.

As the resulting distribution was unsatisfactory, we have grouped together (2) and (3) as being normal, and (4) and (5) below normal, so that we are left with three grades as follows:

I. Takes considerable part in athletics.
II. Takes a moderate part in athletics.
III. Takes little or no part in athletics.

In Table 38 we have given the mean age, weight, pulse rate, systolic and diastolic pressures of the three groups comprising 201 boys. We have also calculated the means of all the expected systolic and diastolic pressures for the individuals comprising each group according to their age, weight, height and pulse rate, using Figs. 17—20. In the case of the systolic pressure the figures do not show any significant variation from the expected values in Classes II and III, but for Class I the actual mean pressure is 4·2 mm. below the expected value, the probable error being 1·3.

It appears from this that after correcting for differences in physical development and pulse rate—for the boys of Class I are much superior in average physique—those boys who are very keen on games and athletics tend to have a slightly lower systolic pressure than other boys. The effect is more noticeable for the diastolic pressure; thus in Classes II and III there is no significant difference between actual and expected values, but in Class I the actual mean diastolic pressure is 6·2 mm. below the expected mean, the probable error being 1·3. There can be no doubt therefore that an athletic habit of

TABLE 38. *Relation between Blood Pressure and Athletics (Secondary School Boys).*

Athletic grade	No.	Mean age	Mean weight	Mean height	Mean pulse rate	Mean systolic pressure		Mean diastolic pressure	
						Actual	Expected*	Actual	Expected*
Class I (keen on athletics)	50	14·64	48·09	161·90	76·67	116·46 ± 1·3	120·66	67·78 ± 1·3	73·99
Class II (normal interest)	92	14·00	42·46	153·59	79·74	118·21 ± ·82	117·49	72·26 ± ·61	72·39
Class III (little or no interest)	59	14·40	46·16	159·50	83·51	119·03 ± 1·15	121·25	73·12 ± ·86	74·24

* i.e. mean of expected values for the individuals comprising these groups taking into consideration their age, weight, height and pulse rate and using Figs. 17—20.

life keeps the diastolic pressure at a lower level during growth, as in adult life, owing probably to diminished peripheral resistance. The systolic pressure being less reduced, pulse pressure is somewhat raised*.

It is regrettable that the classification could not be obtained for a larger number of boys, but the results definitely support the conclusion we have already formed in the case of young adults, that *regular physical exercise tends to keep the diastolic pressure at a lower level, whereas a sedentary mode of life tends to raise it, the systolic pressure being similarly affected, but to a less extent.*

Healthy or Unhealthy Appearance. In the case of some 440 boys we sought to determine whether blood pressure was in any way connected with the general appearance of health, and particularly whether boys of exuberantly healthy appearance and rosy cheeks tended to have higher pressures than the pale-faced boys. To this end we divided the boys into four groups as follows:

Class I. Rosy-faced boys. Class II. Boys of ordinary healthy complexion.
Class III. Sallow-complexioned boys. Class IV. Pale-faced boys.

* For 152 male students classified in the same way the mean diastolic pressures for the three classes were 83·16, 83·19, 86·94 mm., and mean pulse pressures 47·17, 44·46, 39·32 mm.

The average age, weight, pulse rate and observed blood and pulse pressures of these classes are shown in Table 39. It will be noticed that the red-faced boys have an average pulse rate considerably higher than the other groups, though the mean ages of the groups do not vary more than a year; the general average pulse rate at age 11·1 is 82·62.

The mean pressures for Classes I and IV are about 2 mm. below the expected values, whilst for Classes II and III they are not significantly different from the expected values; that is to say, a ruddy complexion in a boy certainly does not indicate a pressure above average (as might perhaps be inferred from the popular phrase "full blooded"); if anything, their average systolic pressure is subnormal. Rosiness of complexion is dependent on the capillary circulation of the surface layers of the skin, which has probably little, if any, connection with the pressure in the arteries. The pale-faced group of boys have, also, an average pressure considerably below the average, a deficiency which is not completely accounted for by their somewhat lower average weight and pulse rate. Most of these boys were of delicate constitution, and some were undoubtedly anaemic; it is not therefore surprising that this type of boy tends to have a subnormal systolic pressure.

The diastolic pressures show no significant differences.

TABLE 39. *Relation between Blood Pressure and Complexion* (*Boys*).

Complexion	No. of cases	Mean age	Mean weight	Mean pulse rate	Mean systolic pressure	Mean diastolic pressure	Mean pulse pressure
Class I. Red-faced boys ...	48	11·12	32·82	86·28	105·42 ± 1·53	66·25 ± ·85	39·17 ± 1·16
„ II. Healthy appearance	434	11·94	36·42	81·46	110·10 ± ·48	67·91 ± ·28	43·19 ± ·39
„ III. Sallow complexion	202	12·30	36·23	83·05	111·34 ± ·70	67·99 ± ·42	43·35 ± ·57
„ IV. Pale faced	55	11·65	33·36	83·80	105·61 ± 1·27	68·36 ± ·80	37·25 ± 1·08

(10) RELATION OF BLOOD PRESSURE TO RESPIRATION.

Lewis (63) found that deep intercostal inspiration produced a fall in blood pressure, whilst deep diaphragmatic inspiration produced a rise. Weysse and Lutz (64) however concluded that the pressure falls during inspiration and rises during expiration, whatever the type of respiration. Foley (65) and others found that considerable variations both of systolic and diastolic pressures could be produced by deep breathing. Sewall (33) found a periodic variation with breathing, with an amplitude averaging some 5 mm., the maximum occurring at beginning of the phase of expiration, whilst Faught (30) states that the maximum occurs midway between inspiration and expiration. Dearborn (39) says that prolonged holding of the breath results in an elevation of blood pressure, and quotes one instance where a subject, by holding his breath for 2½ minutes, raised his systolic pressure by 119 mm.!

In about 110 British male students, we have made measurements of maximum breathing capacity ("vital capacity") and also of the maximum expiratory force, measured by a mercury manometer. We also measured the maximum time during which the subject was able to hold the breath, whilst keeping the pressure in the

manometer at 30 mm. The blood pressure in every case was measured before applying these tests.

Since the body weight and some of the other variables have not reached a steady adult level before the age of 21, we have corrected all readings from the age curves, before correlating.

The correlation coefficients obtained from this group of British males, aged 18—39, are given in Table 40.

These correlations are admittedly based on a small number of cases, and the following conclusions from them are given with some reserve on that account. These conclusions are chiefly negative. Vital capacity has apparently no correlation with systolic or diastolic pressure, and its relation with pulse pressure is slightly negative.

Respiratory force has no correlation with pulse pressure, but may possibly have a small positive relation with the diastolic pressure and possibly with systolic also.

TABLE 40. *Correlation Coefficients between Respiratory and Blood Pressure Variables.* (110 *Males, aged* 18—39.)

		Corrected for age	Corrected for age, weight and height
Vital capacity and	Weight	·452 ± ·051	—
	Height	·422 ± ·053	—
	Systolic Pressure...	− ·082 ± ·064	− ·033
	Diastolic Pressure	·063 ± ·064	·004
	Pulse Pressure ...	− ·111 ± ·064	− ·156
Expiratory force and	Weight	·104 ± ·063	—
	Systolic Pressure...	·107 ± ·063	·098
	Diastolic Pressure	·143 ± ·063	·134
	Pulse Pressure ...	− ·034 ± ·064	− ·040
Fatigue time and	Weight	·113 ± ·064	—
	Systolic Pressure...	·145 ± ·063	·135
	Diastolic Pressure	·031 ± ·065	·020
	Pulse Pressure ...	·139 ± ·063	·133

The respiratory fatigue time, on the other hand, has no correlation with diastolic pressure, but may possibly have a small positive relation to systolic and pulse pressures.

These results are somewhat disappointing, and seem to show that the various capacities and powers of the respiratory system, as measured by these three tests, have very little dependence on the blood pressure. Further data are however required before this can be stated with certainty.

(11) PSYCHOLOGICAL, EMOTIONAL AND MENTAL INFLUENCES.

It has long been observed that such emotions as fear, excitement or nervousness affected the blood pressure. Dearborn (39) concluded from observations on some thousands of adults that blood pressure was raised by anxiety or unpleasant emotions, and lowered by pleasurable sensations.

Potter (66) and Bonsfield (67) pointed out that low pressures are characteristic of certain types of neurasthenia. Bertrand-Smith (16), Lee (7) and others have shown

that, in the case of nervous and highly strung individuals, the first reading of systolic pressure may be in excess of subsequent ones owing to the nervousness occasioned by the unusual nature of the experiment.

Alvarez(46) measured the mean differences in passing from first to second readings on 100 males and 100 females, and found for males an average *rise* of 2·08 mm., and for females an average *fall* of 1·94 mm. These results do not support the view that this factor is in the aggregate of much importance for adults, and we are of the opinion that it is adequately corrected for by applying our pulse rate corrections at any age.

We were interested to determine whether *School Discipline* had any measurable effect on the average blood pressure of the boys, and with this purpose in view, we divided our London Secondary Schools into three groups according to what we believed, from our own observations, to be the strictness of the discipline exercised in these schools.

These groups were:

Class I. Discipline very strict.

Class II. Discipline average.

Class III. Discipline very lax.

We have analysed the mean measurements of boys of age groups 12, 13, 14, and 15 for these three classes, and the results are given in Table 41 and also in Fig. 22.

TABLE 41. *Connection between School Discipline and Average Blood Pressure (Secondary Schools).*

Central age	Class	No.	Mean weight	Mean height	Mean P. R.	Mean systolic		Mean diastolic		Mean pulse pressure		Mean P. P. × P. R.	
						Actual	Expected	Actual	Expected	Actual	Expected	Actual	Expected
12	I	21	35·5	142·3	81·23	112·48 ± 1·91	110·2	69·00 ± 1·27	67·9	46·00 ± 1·75	42·3	3382	3437
	II	24	34·3	141·6	86·29	112·33 ± 1·76	110·1	70·01 ± 1·19	68·5	42·68 ± 1·51	41·6	3701	3590
	III	50	33·7	141·7	83·09	108·93 ± 1·29	109·2	70·57 ± ·84	67·8	40·99 ± 1·16	41·4	3438	3441
13	I	17	36·3	146·2	84·66	113·58 ± 2·20	112·5	66·87 ± 1·35	70·2	47·31 ± 1·54	42·3	3959	3581
	II	25	37·2	147·7	84·75	112·04 ± 1·70	113·1	71·64 ± 1·14	70·6	40·96 ± 1·60	42·5	3567	3602
	III	48	35·6	145·2	85·93	109·16 ± 1·30	112·2	70·43 ± ·79	70·0	39·38 ± 1·14	42·2	3379	3626
14	I	40	43·0	155·0	77·76	122·11 ± 1·39	117·7	74·55 ± ·98	72·9	48·83 ± 1·21	44·8	3870	3483
	II	66	41·7	154·9	83·82	111·98 ± 1·07	117·8	71·88 ± ·74	73·1	40·50 ± ·92	44·7	3484	3746
	III	21	41·0	153·3	85·60	115·12 ± 1·91	117·6	71·49 ± 1·34	72·8	43·35 ± 1·65	44·8	3707	3835
15	I	60	49·5	161·5	76·27	124·49 ± 1·13	123·2	73·19 ± ·95	74·9	52·70 ± 1·08	48·3	4087	3684
	II	23	48·1	160·6	80·14	119·96 ± 1·72	123·1	71·68 ± 1·54	74·8	48·32 ± 1·65	48·3	3874	3870
	III	15	46·4	162·5	80·12	120·43 ± 2·29	122·3	77·43 ± 1·80	75·2	43·23 ± 2·12	47·1	3571	3773

The class differences in diastolic pressure are not significant in view of the size of the probable errors, but in the case of the pulse pressure, and to a less extent of the systolic pressure, there is a definite rise in pressure indicated in passing from Class III to Class I, which occurs constantly in each age group, and averages for the whole as much as 7 mm. for pulse pressure, and 4·7 mm. for systolic pressure. This is more clearly indicated in Fig. 22, where the dotted line shows the general averages for the three classes combined, whilst the points for Classes I and II are

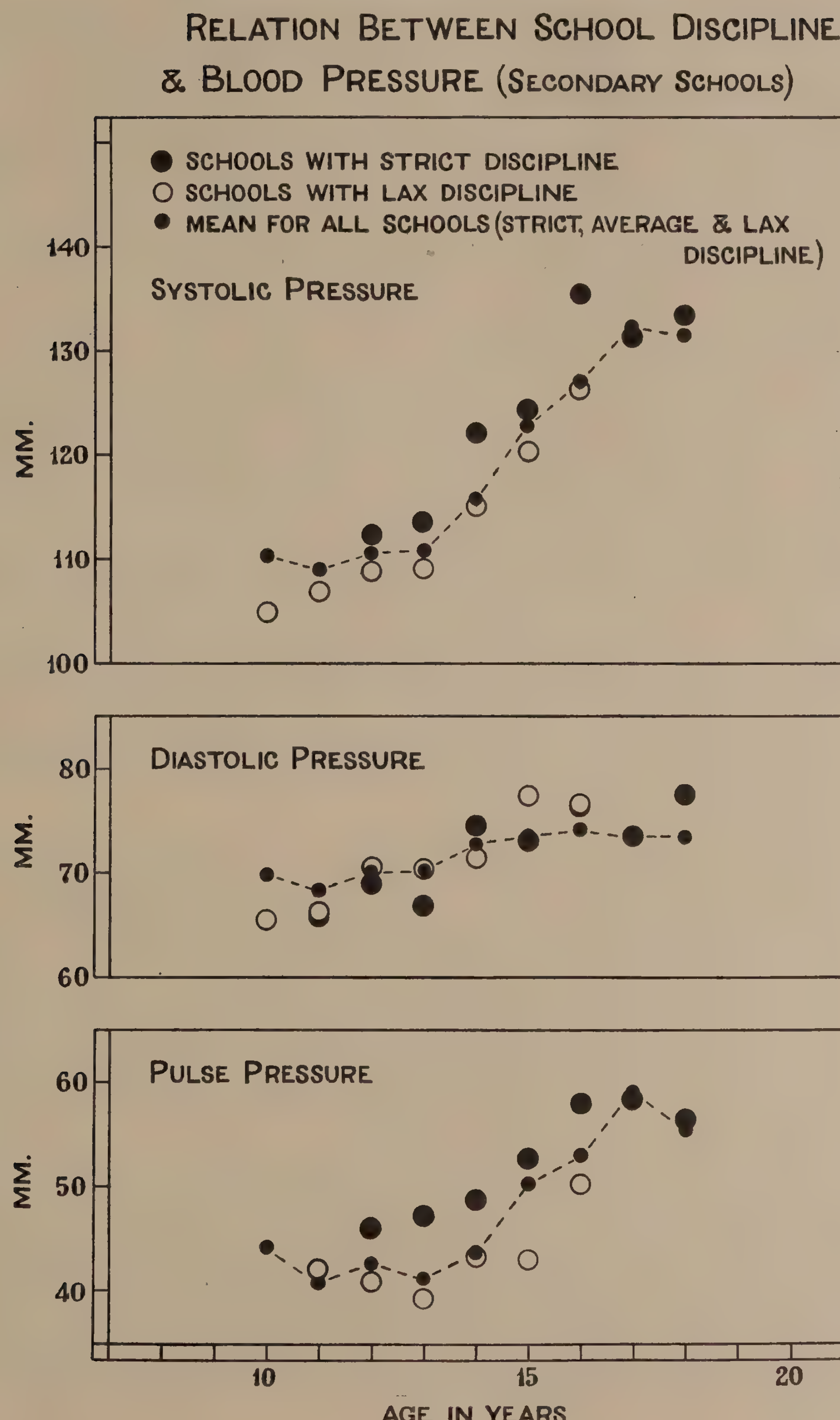

RELATION BETWEEN SCHOOL DISCIPLINE
& BLOOD PRESSURE (SECONDARY SCHOOLS)
SCHOOLS WITH STRICT DISCIPLINE
SCHOOLS WITH LAX DISCIPLINE
MEAN FOR ALL SCHOOLS (STRICT, AVERAGE & LAX DISCIPLINE)
SYSTOLIC PRESSURE
DIASTOLIC PRESSURE
PULSE PRESSURE
MM.
140
130
120
110
100
80
70
60
50
40
10
15
20
AGE IN YEARS

FIG. 22.

marked separately. The divergence in systolic pressure between Classes I and III at all ages cannot be accounted for by the weight and pulse-rate differences of the classes, for these tend to counteract each other, and the expected differences between the class means on this basis never exceed 1 mm. (see Table 41).

The boys of Class I type of school are of slightly superior physical development, a fact probably explicable by some stricter form of selection in these schools. The mean pulse rates are significantly lower for Class I than Class III in each age group, the difference averaging 3·7 beats per minute. Consequently the "cardiac output" product does not show so definite a class difference as the pulse pressure alone, since the components are oppositely affected.

There seems therefore no doubt that *the effect of strict school discipline, as compared with very lax discipline, on boys between* 12 *and* 15 *is to raise the pulse pressure but not the diastolic pressure, and, in compensation, steady the pulse rate, both of which produce a general bracing up of the vaso-motor system during school hours.*

Such a bracing up and steadying of the heart's action cannot but be of value in the development of the normal growing boy, but to the delicate and nervous boy, in whom the effect must necessarily be exaggerated and the vaso-motor mechanism less able to respond to it without fatigue, it seems to us that a too strict school discipline may be harmful. We would therefore point out the importance of selecting a suitable school in these cases, since a psychological atmosphere which may be "bracing" and beneficial to the normal, may be too stimulating and actually harmful to the delicate and highly-strung boy, by putting too great a demand upon the circulatory as well as upon the nervous mechanism. We may remark here in this connection, that the only cases of syncope which occurred during our investigation were in boys of this type in a school of Class I.

Mental Capacities and Blood Pressure.

In the case of 140 boys and students, we have correlated the systolic pressure with performance in a series of "mental" tests. These tests were as follows:

(1) Speed of substituting symbols in the spaces beneath a series of 100 digits, a key for the substitutions being provided during the tests.

(2) A speed and accuracy test, requiring the cancelling of complex "hieroglyphics" consisting of numbers, letters, dots, circles and squares according to a given plan involving the fixing of certain associations in the mind.

(3) Memorizing a 3-dimensional arrangement of small cubes after an exposure of 30 seconds.

(4) Speed and accuracy in counting the number of cubes in a pile.

(5) A test designed to measure accuracy in judgment of length, size and number.

The correlation coefficients of systolic pressure with these five tests were respectively $\cdot 05 \pm \cdot 05$, $-\cdot 02 \pm \cdot 05$, $+\cdot 13 \pm \cdot 05$, $\cdot 05 \pm \cdot 05$, $\cdot 08 \pm \cdot 05$ after correcting for the age factor, and none of them appear to be significant.

With a test designed to measure steadiness of hand and precision of aim, systolic pressure gave a correlation coefficient of $\cdot 07 \pm \cdot 05$.

With a mean grade in the performance of five tests measuring sensory discrimination, the correlation coefficient was ·01 ± ·05.

We have not therefore as yet succeeded in finding any significant relation between blood pressure and individual psychological tests of this kind.

(12) Sex.

It has long been noticed that the average arterial pressure is somewhat lower in females than males of adult age. Oliver (40) states that the systolic pressure is usually about 10 mm. lower in females, and the diastolic about 5 mm. lower. Janeway (68) showed from some 2000 observations that the average adult sexual difference was about 10 mm. for systolic pressure, whilst Woley (47) obtained an average of 7·5 mm. Faught (30) states that the difference rarely exceeds 5 mm. in children.

The best comparative data are those of Alvarez (46) and Faber and James (54). The first-mentioned observer compared 2930 male and 5807 female students in California, measuring by the palpatory method in the recumbent position; he found a difference of 10·5 mm. at age 16, and differences varying from 10 to 12 mm. at subsequent ages. Faber and James, using the same method as our own on 651 boys and 450 girls, found on the other hand no significant difference between the sexes either in systolic or diastolic pressure up to age 16, where their observations ceased. There is a remarkable discrepancy between these two results for age 16, but, as we have remarked, the figures which the last-mentioned authors obtained for American boys are much lower than those found by ourselves or other workers.

Table 42. *Female Students (British). Averages for different Ages.*

	Age centred at						Age group		All cases	Males*	Difference	
	19	20	21	22	23	24	25—29	30—35	20—35	20—35	Actual	Expected†
No. of Cases	10	26	20	19	8	5	12	8	98	—	—	—
Weight ...	59·15	58·41	57·35	58·79	57·45	60 35	57·95	54·45	57·9	64·3	− 6·4	—
Height ...	165·1	163·5	165·0	164·1	160·9	163·0	161·7	157·2	162·9	174·3	−11·4	—
Pulse Rate ...	86·1	79 9	79·1	80·1	84·9	82·5	78·9	77·9	79·8	72·5	+ 7·3	—
Systolic Press.	119·9	121·3	121·1	122·0	124 0	116·3	122·2	122·0	121·7	129·6	− 7·9	+2·1
Diastolic Press.	86·7	83·2	79·5	81·5	80·0	76·7	77·5	83·0	81·8	84·5	− 2·7	−2·2
Pulse Pressure	33·2	39·1	42·6	40 5	44·0	39·6	44·7	39·0	39·9	44·8	− 4·9	+4·3
P. P. × P. R.	2800	3077	3225	3262	3687	2700	2834	3187	3183	3258	−75	—

* Students only. † i.e. on the basis of differences in physical development and pulse rate alone.

We do not propose to deal in this paper with the question of sex differences in any detail, as we have only so far data for 108 British female students for comparison with the male data. We have divided these into age groups from 19 upwards, and have given in Table 42 the average weight, height, pulse rate and blood pressures at each age. The point we have sought to determine is whether the sexual difference in average blood pressure is merely accountable for by differences in physical development and pulse rate, or whether there is some other factor involved.

Table 42 indicates that neither systolic, diastolic nor pulse pressure shows any definite tendency to increase or decrease between 20 and 35, and the same applies to the pulse rate and cardiac output product.

In the last columns we have given for comparison the means for females and males of ages 20—35, and the actual differences between the sexes. The mean weight for females is about 6 kgms. lower, and the mean height 11 cm. less than for males, whilst the average pulse rate is 7 beats per minute higher. The mean systolic pressure is 8 mm. lower in females, whereas the difference expected on the basis of weight and pulse rate is an excess of 2 mm. Hence we must conclude that there is, apart from differences due to unequal physical development and quicker pulse rate in females, an innate difference between the sexes as regards systolic pressure amounting to about 10 mm.

In the case of diastolic pressure, the difference of 2·7 mm. can be almost accounted for by the inferior height, the expected difference from this factor and pulse rate combined being 2·2 mm.

It is noteworthy that the average pulse pressure × pulse rate product is practically the same in both sexes within the limits of probable error.

TABLE 43. *Correlation Coefficients for Female Students* (*Ages* 19—34).

	Weight	Systolic pressure		Diastolic pressure	Pulse pressure
		Uncorrected	Corrected for weight		
Weight	—	·173 ± ·062	—	·133 ± ·063	·052 ± ·063
Height	·626	·075 ± ·063	− ·056	·092 ± ·063	− ·048 ± ·064
Pulse rate ...	—	·031 ± ·063	—	·171 ± ·062	− ·139 ± ·063
Hand grip ...	·457	·134 ± ·063	·063	—	—
Strength of pull ...	·254	·082 ± ·063	·039	—	—
Vital capacity ...	·209	·158 ± ·062	·124	—	—

In Table 43 we have given correlation coefficients between blood pressure and a few other variables for 108 female students for comparison with the corresponding coefficients for males. The correlation of weight with height is ·626 (males ·669); of weight with hand grip ·457 (males ·456); of weight with pulling strength ·254 (males ·363); of weight with vital capacity ·209 (males ·452). The correlation of systolic pressure with weight is ·173 (males ·118); with height ·075 (males ·018); with pulse rate ·031 (males ·350); with hand grip corrected for weight ·063 (males ·330); with pulling strength, corrected, ·039 (males ·149), and with vital capacity, corrected, ·124 (males − ·033). The most remarkable feature about these results is the absence of correlation between pulse rate and systolic pressure, which in males is considerable. The correlation with hand grip is also insignificant, though for males it was ·33.

Diastolic pressure gives a coefficient of ·133 with weight (males ·127); ·092 with height (males ·141) and ·171 with pulse rate (males ·250). Pulse pressure has no correlation with weight and height and a negative relation with pulse rate, − ·139, as compared with + ·172 for males. The number of cases is too small to base any

very firm conclusions upon, and we hope to obtain further data to confirm the apparent sex differences in the relations of blood pressure with pulse rate.

(13) Pathological Conditions.

We are not concerned with the effect of pathological conditions on the blood pressure, except to emphasize the importance of having a better knowledge of what limits may be safely considered as normal in any individual, before deciding that an observed reading is of pathological significance in his or her case. It is hoped that Tables 8, 30, 31 and Figs. 17—20 may be of some assistance in this direction.

In our series of school boys we came across 13 cases with undoubted heart lesions, which we have excluded from our statistical data. Four of these had aortic incompetence, three of them being under observation by the School Medical Officer. The latter were boys aged 15, with systolic pressures respectively 148, 143 and 168 mm.; one of them gave a pulse pressure × pulse rate product as high as 9400! The fourth case was a boy aged 13; he had recently been examined by the School Medical Officer, who had not detected anything abnormal; he had no symptoms suggesting valvular disease and took part in school games and gymnastics. He was found to have systolic pressure 170 mm. which was not reduced on repeating the measurement; diastolic pressure 78, pulse pressure 92, pulse rate 83, cardiac output product 7664. As these readings were unquestionably pathological we called the School Medical Officer's attention to him again, and on re-examination he was found to have a definite aortic bruit, with other signs of aortic incompetence. Such a case was of course in imminent danger whilst engaging unchecked in school games and gymnastics, and brought home to us the usefulness of routine blood pressure measurements in picking out such cases, which are notoriously difficult to detect by the stethoscope, especially in the noisy environment in which many school medical inspections have perforce to be carried out. In this connection we will mention another case of a boy aged 14 who had been several times absent from school with alleged "fits." The boy's and his parents' description of these attacks was somewhat suggestive of epilepsy, but having had no such attacks in school, the diagnosis was in doubt. The thyroid was slightly enlarged and the hands slightly cyanosed. The systolic pressure was 104 mm., diastolic 70, pulse pressure 34, pulse rate 78, product 2660. These low readings did not support the idea of epilepsy but rather of myocardial weakness, and on further examination the heart was found to be considerably dilated to the right. This knowledge again was of considerable help both to the Medical Officer and the Headmaster in showing how to deal with the boy. These two cases are sufficient illustration in our opinion of the value of blood pressure determinations in detecting pathological heart conditions in boys of Secondary School age; but we consider that, from the point of view of *preventing* cardiac overstrain during adolescence, its routine use in the Medical Inspections of Secondary Schools at this period would be of still greater value.

It has been found by Martin (71) and others that a rise in blood pressure is liable to occur in children in the course of *convalescence after fevers*; such a rise may amount to 10 or 20 mm. and be accompanied by apical murmurs.

This suggested the possibility that severe attacks of scarlet fever and other exanthemata in childhood might conceivably have a permanent influence on the pressure. In order to test this possibility from our data, we obtained records of the number of exanthemata in the past history of some 350 of the boys, and have in Table 44 classified these boys into age groups, and also according to the number of fevers, confining ourselves to scarlet fever, diphtheria, measles, whooping cough and chicken pox.

The number of cases in many of the resulting cells of the table being very small, we have entered the deviations of the mean of the group from the corresponding age average, and in the last column have calculated the weighted mean deviation from the age curve for all ages. The probable errors of the latter figures are of the order 1·5, ·7, ·8, 1·0 and 2·7 mm., so that it cannot be said that there is any conclusive evidence from these figures of any permanent effect of the exanthemata on the systolic pressure in after life.

TABLE 44. *Effect of Exanthemata in Childhood on Systolic Pressure.* (*Scarlet fever, diphtheria, measles, whooping cough, chicken pox.*)

	Deviations of group means from standard for age, in mm. of pressure. Age centred at								Mean deviation for all ages
	7	8	9	10	11	12	13	14	
No fevers ...	(2) + 8·00	(3) + 3·44	(2) − 4·80	(3) + ·28	(3) − ·28	(4) − ·32	(2) − 3·48	(10) − 3·08	(29) − ·776
1 fever ...	(11) − ·92	(24) + ·20	(15) + 2·68	(14) + ·56	(11) + 4·80	(30) − 2·96	(27) − ·28	(16) + 3·20	(148) + ·302
2 fevers ...	(6) + ·68	(15) − 1·72	(8) + 3·20	(7) − 5·44	(8) − 2·80	(8) − 8·96	(22) − 1·84	(21) − ·96	(95) − 1·960
3 „ ...	(6) − 1·32	(10) + ·68	(6) + 3·84	(11) + 1·00	(3) + 3·72	(2) + 4·52	(12) + 1·84	(14) − 3·16	(64) + ·452
4 or 5 fevers		(2) + 2·68	(1) + 7·20	(2) + 8·28	(2) − 6·28			(2) − 2·28	(9) + 1·380

Figures in brackets are the number of cases.

SUMMARY OF CONCLUSIONS.

(1) The whole question of blood-pressure measurements and their significance has fallen into a state of confusion, from which we have endeavoured in this paper to do something towards rescuing it. A continuous series of observations covering the period of adolescence has not hitherto been published, and we have tried to bridge this important gap and obtain continuous age curves for males from ages 5 to 40.

(2) We strongly urge the importance of adopting in this country a standard method of measuring arterial pressure, since otherwise comparison between the results of different workers is impossible.

(3) We consider that as regards technique, the auscultatory method is far more reliable than the palpatory, and find that the latter method gives readings for systolic pressure averaging 14 mm. below the auscultatory method in young adults, the discrepancy being less in children. For the diastolic pressure we are convinced both from the experimental evidence, and from our own experience, that the best index to use is the end of the third phase of sound ("4th point"), marking the change from a clear to a dull sound, audible on gradually releasing the pressure of the armlet.

(4) We therefore advocate the use of the following method in blood-pressure work. Subject in sitting posture, with left arm resting relaxed on table in front, palm

upwards; use of sphygmomanometer with standard 12 cm. armlet applied round left arm above elbow, end of stethoscope being applied by elastic band (not too tightly) to bend of elbow. Readings to be taken as pressure is released; systolic pressure at 1st and diastolic at 4th point (or "5th" when 4th is not distinguishable). Where possible morning readings are advocated.

(5) The changes which occur in pressure and pulse rate on rising from sitting to standing posture are widely variable in different individuals, the mean effect in males being a rise of 3 mm. in systolic and 10 mm. in diastolic pressure, and a rise of 7·5 beats per minute in pulse rate, with a fall of 7 mm. in pulse pressure, leaving the average product of pulse rate and pressure slightly lower. In females there is no average rise in systolic pressure, and that of diastolic averages only 5 mm., but the changes in pulse rate and pulse pressure are similar to those in males. We find no evidence that these reactions can be taken as an index of physical fitness.

(6) Observations on a limited number of foreign students lend support to the view that there is a racial difference in average systolic pressure, which is still manifest after residence in a common climate and environment.

Social class also has a very considerable influence on the systolic and pulse pressures, which is not fully explained by superiority in physical development.

(7) The commonly accepted rule that blood pressure rises more or less uniformly throughout life is not supported by our observations. Up to 11 years of age the mean systolic pressure rises uniformly with age; during adolescence the gradient is temporarily increased and the pressure attains a uniform adult level at about 18 years of age, showing no further tendency to rise up to the age of 35 or 40. The diastolic pressure rises more or less uniformly till adolescence, then more slowly to 17 when it commences to rise rapidly to a maximum about 20, after which it slightly falls again to 35.

Pulse pressure rises uniformly to 15, but during adolescence rises to a considerable maximum at about 16 to 18 years of age, then rapidly falls to its original level about 20, and afterwards slowly increases up to 40.

The onset of puberty therefore accentuates the systolic gradient and depresses the diastolic, so that pulse pressure is rapidly raised; towards the end of adolescence diastolic pressure rapidly rises and pulse pressure falls.

(8) The large increase in pulse pressure, and consequently of kinetic work being done by the heart during adolescence, seems to indicate that during this period, and particularly about the age of 16 and 17, the heart is performing more work per unit weight of cardiac muscle than at any preceding or subsequent period of life up to 40. This we believe to be connected with the fact that the rate of growth is also at its maximum at this time.

(9) Systolic pressure and, to a less extent, diastolic pressure are positively correlated with the pulse rate when other factors are constant, the amount of this correlation varying with age. By applying the appropriate age correction for an abnormally high pulse rate arising from nervousness, the effect of this last factor can be partly eliminated.

(10) Blood pressure is correlated with bodily development apart from age. The systolic pressure is positively correlated with body weight, but not with height when other factors are constant, whereas the reverse is the case for diastolic pressure.

By means of correction curves and tables the limits of probable normality for an individual of known age, weight, stature and pulse rate have been defined, and can be quickly read off (see Figs. 17—20 and Tables 30, 31). By this means the range of variability is somewhat reduced, but is still considerable since other factors such as social class and heredity are involved.

(11) Systolic pressure is positively correlated with muscular strength after correcting for age and physical development; whether one is dependent on the other, or both are dependent on a common factor, remains uncertain.

(12) Regular physical exercise tends to keep the diastolic pressure at a lower level, by reducing peripheral resistance, and thereby renders the heart more efficient; a continuance of such regular exercise after adolescence probably delays the rise of diastolic pressure to the adult level, which usually occurs when a more sedentary mode of life is commenced.

(13) We find very little evidence of correlation between vital capacity or efficiency in tests of respiratory force, and blood pressure.

(14) The psychological influence on blood pressure is of considerable importance, and our observations lead to the conclusion that, in schools where a strict discipline is maintained, the average systolic and pulse pressures of the boys are appreciably higher than in the more easy-going school, whilst the pulse rate is reduced in compensation.

(15) A somewhat limited number of observations on female students show that the systolic and pulse pressures are uniformly lower than in males between ages 19 and 34, by about 8 mm., a deficiency which cannot be accounted for by differences in average physical development and pulse rate. The diastolic pressure shows no difference attributable to sex, and the pulse pressure rate product is the same as in males.

(16) The routine measurement of blood pressure in growing boys proved in several instances the means of diagnosing serious heart lesions which would otherwise have passed unnoticed. The search for evidence of any permanent effect of exanthemata upon the blood pressure of boys proved negative.

In conclusion we desire to express our indebtedness to Professor Karl Pearson for his invaluable help and advice in many difficulties we encountered; to the Education Committee of the London County Council for permitting this work to be undertaken in the schools; to the School Medical Department and Officers for their courteous assistance in the arranging and carrying out of the work in Secondary and Elementary Schools in London; to the Headmasters of the various schools visited for their helpful cooperation in the actual examinations; to the Headmaster of Merchant Taylors' School and the senior boys for kindly allowing the tests to be carried out on a large number; and to the Management of the Virol Company for giving permission for tests to be carried out in their Factory at Ealing.

We are also indebted to the School Medical Officer at Bristol for enabling us to undertake some preliminary measurements in Secondary Schools, which provided the incentive for this research.

We must also thank Miss Ida McLearn for her patience in the drawing of all the diagrams in this paper, Miss Moul for her assistance in curve fitting, and Mr E. S. Pearson for carrying out some of the muscular tests which we have utilized in this research.

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